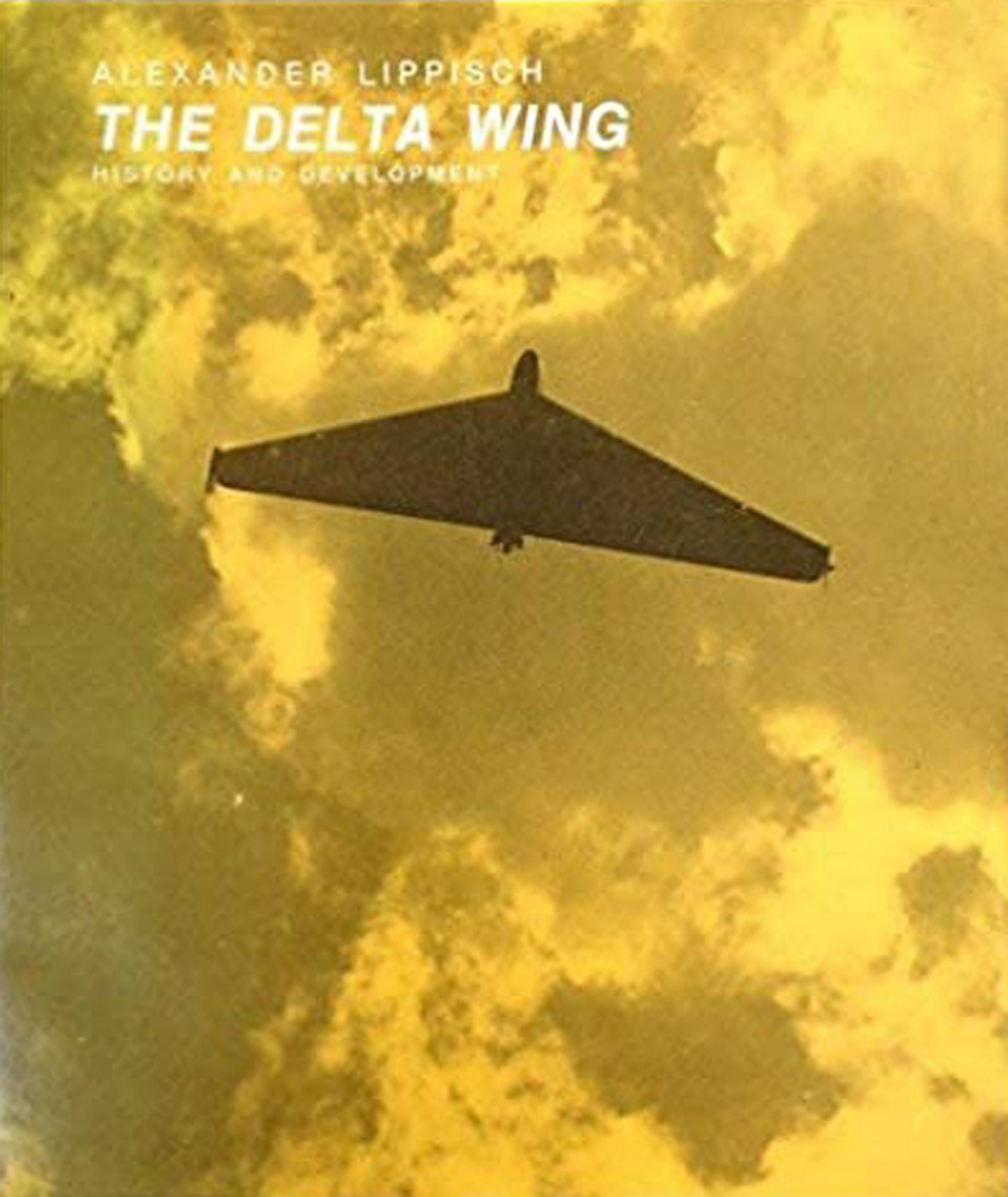
ALEXANDER LIPPISCH

THE DELTA WING

HISTORY AND DEVELOPMENT



ALEXANDER LIPPISCH
Translated by Gertrude L. Lippisch

THE DELTA WING
History and Development

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Preface

TWENTY YEARS of development were needed to prove that the tailless aircraft with Delta wing (i.e., a wing of triangular planform and straight trailing edge) which more or less approaches the perfect all-wing or flying-wing concept, is equal to and for certain applications superior to the normal airplane. This is borne out by the fact that many of today's supersonic aircraft use the Delta wing, possibly with some additional refinements.

More than half of the 90-odd aircraft that I designed in my lifetime were tailless types. Of this total about 30 reached the flying stage, some of them in different versions. A number of the remaining projects were tested in the wind tunnel and some were built in mock-up form.

Since the development of these aircraft and aircraft projects was carried out at different research institutes and at a few aircraft companies, there is no uniform, complete record. Reports on individual projects were often written without knowledge of essential relationships and are subject to inconsistencies.

It is the object of this book to present the difficult history of the development of the Delta wing in concise form. Therefore theoretical observations will be presented only where they are absolutely necessary to the understanding of the different stages of development. In the last chapter a few "outsider" designs will be introduced, among them the extreme opposite of the flying wing, namely a wingless flying vehicle—the *Aerodyne*—which reached an advanced stage of development. Readers interested in more technical information will find it in the tables and graphs of the Appendix. For more detailed background we refer to the publications listed in the Bibliography.

I would like to express my gratitude to those who gave me assistance in the preparation and writing of this book. To Fritz Trenkle, Fürstenfeldbruck, West Germany, I owe the stimulus for this documentation of the development of Delta wing airplanes and many constructive suggestions for the outline. In addition he supplied missing data, reports, and illustrations, which he had compiled over a period of many years. He also procured new three-view drawings where the old ones were no longer fit for printing. For a critical review of the text, valuable additions, and some pictures I am indebted to my former associates Walter Beushausen, Dr. Hermann Wurster, Heinrich Körner, and Mr. Radinger, who are now living in Augsburg; also to Mr. Stender of Germering, Dr. Wilckens of Unterpfaffenhofen, Mr. Schliephake of Königsbrunn, and H. J. Meier of Bremen.

There is no doubt that it would have been impossible to bring this development work, which lay so far from the common path, to culmination in a workable technical product without the unconditional support of my coworkers, who persevered even in seemingly hopeless situations. This book is a recognition of *their* work as well and represents part of the thanks I owe them.

Alexander Lippisch

Introduction

A STANDARD AIRCRAFT consists of wing unit, fuselage, and tail unit (*Drachenflugzeug*). Almost without exception our airplanes belong to the subgroup of "normal" type aircraft, where the wing unit is placed in front of the tail unit. By installing the tail unit in front of the wing we obtain the "canard" type as a second subgroup. If the wing unit is reduced in size in favor of the control unit, we obtain the subgroup of "tandem" aircraft (Fig. 1).

If, in order to obtain improved aerodynamic quality and simplified structure, all horizontal surfaces are combined in one structurally stable wing, we obtain three corresponding types of "tailless" aircraft. The "canard" becomes the "buzzard" type with forward (negative) sweep of the wing, comparable to the buzzard's wing position in circling flight. The tandem aircraft becomes the inherently stable wing without any sweep, the "flying board." The normal aircraft type converts into the tailless aircraft with swept-back wing, i.e., a wing with positive sweepback. A special case in this group is the tailless Delta airplane with straight trailing edge. If in the latter type the wing is of sufficient thickness to envelop the fuselage wholly or in part, we obtain the "all-wing" airplane, or flying wing. In the last mentioned Delta types we will however admit the use of vertical stabilizers and control surfaces, departing from opinions that take a different stand. Experience has shown that without these vertical surfaces it is impossible to obtain a degree of directional stability comparable to the normal aircraft type.* Swept-back wings have also been used on high-speed airplanes of normal design, giving rise to a great number of intermediate types, which I will not be able to discuss here.

The great diversity of airplane types that existed in the early years of aviation came to an end shortly before World War I when the normal type airplane, which had been bred for purely military use, established itself. None of the pioneer aircraft companies could afford time-consuming and expensive experiments if they wanted to survive. The normal aircraft type therefore reached a state of refinement which was hard to catch up with. If anybody dared to introduce basically different designs, he ran the risk that his still immature constructions would be compared with the normal type airplane which had been developed through many years of experience. Promising developments were therefore often killed before they had time to mature. This danger was intensified by the fact that the theory of aerodynamics was still in its infancy compared with practical experience. It took courage and steadfastness to stray from the common path.

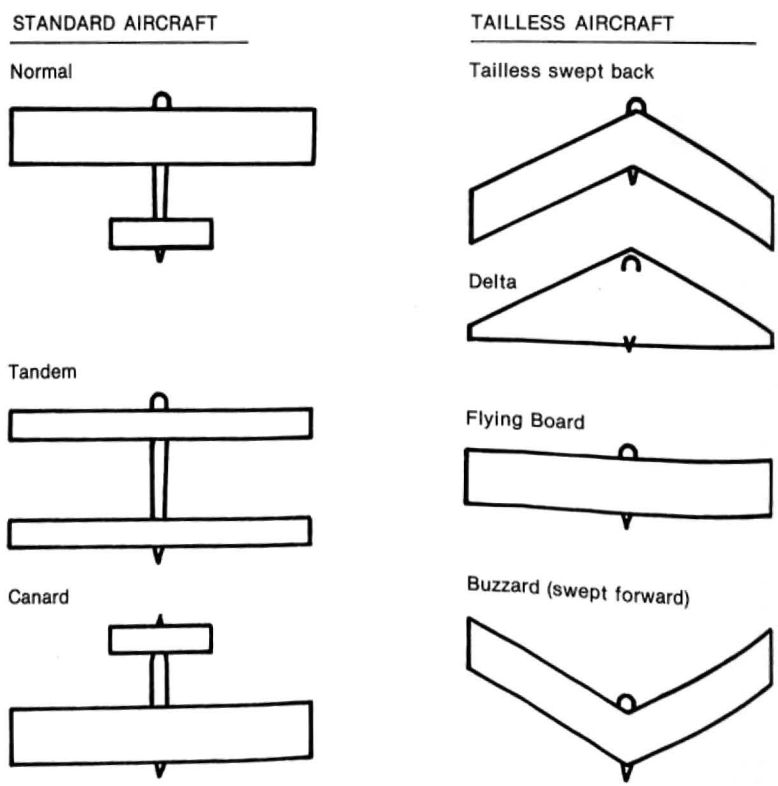
What, in essence, led me to work on the development of tailless airplanes? Eliminating the tail unit including its supports promised a substantial decrease of undesirable aerodynamic drag, i.e., higher speeds at equal engine output. In addition, the structure would be lighter and simpler, insuring reduced construction costs and lower airplane weight at equal payloads. Overall performance and cost efficiency could be expected to improve. The problem now consisted of combining these gains with good or superior flying characteristics. This could only be achieved in small successive steps. Incorporating a number of untested changes simultaneously would without a doubt lead to failure.

*Most birds do not have vertical control planes and usually fly with an unstable wing condition which is constantly corrected.

As a first step I decided to improve the tailless high-wing type (*Stork* type) in order to obtain satisfactory performance, first in gliding and subsequently in powered flight. After this was accomplished, the *Delta* wing could be used as a forerunner of true all-wing aircraft, since a large angle of sweepback allows considerable thickness of the midwing section, which will then envelop a large part of the fuselage. A large size wing of this kind makes it possible to store all loads within its structure.

My efforts had always been aimed at high-speed powered aircraft since, in my opinion, all-wing types are not suited for gliding and soaring flight. On the one hand, gliders demand a wing with high maximum lift, for which the all-wing plane is not suited. On the other hand, they need wings with a high aspect ratio, which on tailless types would lead to poor flying characteristics. On tailless aircraft, control is exercised by wing flaps; and on wings of large span, control effectiveness is insufficient even on wings of high rigidity. When in later years engines of substantially higher performance became available, a relatively thin Delta wing with a large angle of sweepback proved to be the best choice for obtaining high subsonic speeds. That this wing, with some refinements, also shows marked advantages at multiples of the speed of sound has been proven by several postwar aircraft, of which the *Concorde* is the best known.

Fig. 1. Development of tailless aircraft from traditional designs, drawn in 1930. In later years some aircraft with traditional fuselage were also given swept-back wings, which led to a multiplicity of mixed designs.



1 First Experiments with Tailless Aircraft

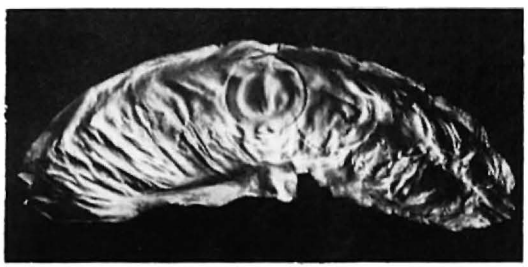


Fig. 2. Flying seed of *Zanonia macrocarpa*.

THE FLYING WING has its origin in an invention of nature, the flying seed of the tropical climber *Zanonia macrocarpa* (Fig. 2). The first account of the amazing flight performance of this seed was given by Professor Ahlborn in 1903 in his article "Gliding Flight." The Austrian Igo Etrich was inspired by this publication and set out to build flying models and a glider airplane following the design of the natural prototype (Fig. 3). His flight tests proved the effectiveness of the stabilizing principle of the *Zanonia* seed. Other pioneers experimented along these lines. In 1910 the Englishman Dunne built a powered tailless aircraft, and in 1913 Hugo Junkers published a patent for an all-wing aircraft.

My own interest in aeronautics began in my earliest youth. Growing up in Berlin I had the unforgettable experience of witnessing Orville Wright's flight demonstration in September 1909 when I was a schoolboy of fourteen (Fig. 4). I eagerly read all available literature on the pioneering attempts to master human flight. The reports on successful flights with inherently stable wings especially attracted my interest. The outbreak of World War I thwarted my professional plans. I served in the infantry and later in a unit for aerial photogrammetry until 1918, the fourth year of the war, when I received a military order to report to the Zeppelin Works in Lindau on the Lake of Constance. I was to be employed as an "aerodynamicist" in the aircraft department which Graf Zeppelin had founded in 1914 under the directorship of Dr. Claude Dornier. I had access to all the available literature on the subject of aerodynamics, a science which was then still in an early state of development, and I gained valuable insights from this work.

The end of the war caused the shutdown of the German aircraft industry, and I turned to other endeavors. In 1921, however, I received a commission to design a sailplane and was therefore able to take part in the gliding contest on the Wasserkuppe/Rhön. Again I was able to turn to the devel-

Fig. 3. Glider by Etrich (around 1906).

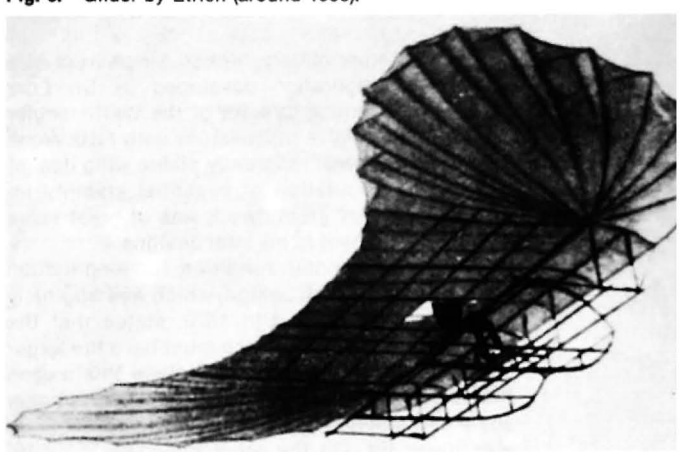


Fig. 4. Flight demonstration by Orville Wright in Berlin on Sept. 1, 1909. Drawing by Lippisch who was then 14 years old.

opment of aircraft designs and to experiment with wings of inherent stability.

My interest in all-wing aircraft design had been newly awakened by the successful flights of the Weltensegler gliders, whose wings were of a gull-type configuration developed by Dr. Fritz Wenk, the technical director of the Weltensegler Company. Extensive discussions with Fritz Wenk on the principles of inherently stable wing design led to the formulation of essential stability requirements. This groundwork was of great value in the development of my later designs.

The fundamental condition for longitudinal stability of an aircraft design, which was originally determined by Pénaud in 1870, states that the front wing or control surface must have the larger specific lift. For the normal airplane this means that the elevator surface must have the smaller angle of incidence or an airfoil section that generates lower lift. On the other hand, the forward-lying control surface of a canard airplane must have a higher angle of incidence. Inherently stable swept-back wings need smaller incidence at the wing tips or lower cambered airfoil sections. The Weltensegler wing fulfilled this condition by setting the outer wing parts at a negative angle to the midwing section (Fig. 5).

The Weltensegler wing was inspired by the outline of the soaring seagull. It certainly is an elegant design, but the conditions for structural strength are difficult to fulfill and entail major disadvantages. Therefore from the beginning I decided to devote myself to the aerodynamic and structural development of the simple swept-back wing. The first glider of this type was the seat-glider *E2,* which was built by Gottlob Espenlaub according to my specifications in the year 1921.

Since the displacement of the center of pressure characteristic of normal cambered airfoil sections would cause considerable torsional stress along the wing, I used a symmetrical section (Gött. 410). The midwing had positive dihedral, and the ailerons were cambered. End plates installed at a downward angle supplied directional stability (Fig. 6). The test flights which Espenlaub performed with this seat-glider were not very impressive and seemed to show that the use of symmetrical sections impairs aerodynamic performance. The glider had been built under very primitive conditions and had other faults as well. In order to be able to use more appropriate airfoil sections and at the same time have control over the torsional stress of the wing, I applied a variation of sections along the wingspan. In 1918, while still working at the Aerodynamic Department of the Zeppelin Works (Dornier), I had developed a systematic series of aerofoil sections with variations of curvature and thickness ratio, which had been measured in the wind tunnel of the Aerodynamic Testing Center (AVA), Göttingen. On the basis of the results of these measurements it was possible to calculate the longitudinal stability of a swept-back wing with variation of profiles along the wingspan. These findings, which were confirmed by experimental tests, are recorded in a general theoretical report which I wrote in the winter months of 1921–22. In later years these insights were applied in my development of tailless and Delta aircraft. At the time, I was only able to

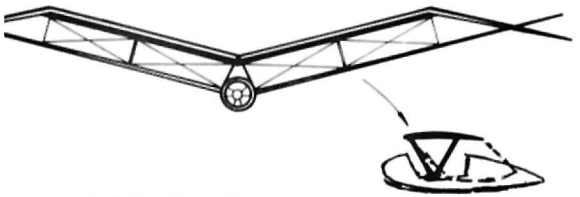


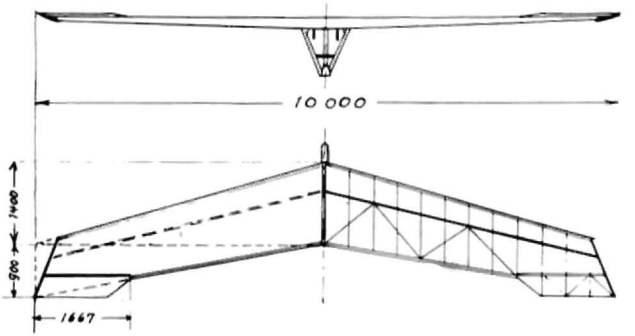
Fig. 5. *Weltensegler* glider by Wenk. The outer wing sections are bent backward and downward.

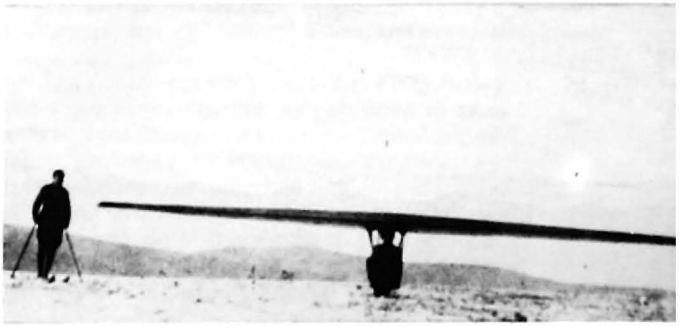
corroborate my theoretical findings by tests with flying models instead of full-size aircraft, since I was primarily occupied with the design and construction of sailplanes for the Weltensegler Company (see below).* Not until the year 1924, after

Fig. 6. Tailless glider Lippisch-Espenlaub *E 2* (1921).

my move to the Steinmann Company in Hagen, Westfalen, did I have the opportunity to continue my work of 1921–22 on the design of swept-back

*Prandtl-Wieselsberger-Betz, "Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen" (Results of the Aerodynamic Testing Center in Goettingen), *AVA-Lieferung 1920.* R. Oldenbourg, München and Berlin.





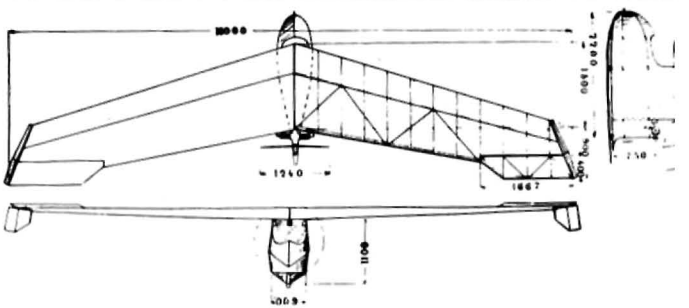


Fig. 7. Glider *Experiment:* (*Above*) layout; (*Center*) glider before attachment of the end plates; (*Below*) projected motorized version.

wings. The glider *Experiment* (Fig. 7) had a swept-back wing with variation of the profiles along the span. The ailerons doubled as elevators and were controlled separately, eliminating the need for rudders. In several flights I tested the wing in combination with a simple open fuselage structure. The motorized version, shown in Figure 7, was never flown, since the tests had to be suspended due to the liquidation of the Steinmann Company [6]*

At this point I would like to give a short overview of the gliders and sailplanes of normal layout which I designed during that early period. My first design was the glider *Falke* in the spring of 1921. Its aerodynamic characteristics were good, but it was plagued by structural defects. The wing of this glider was subsequently tested as a hang-glider, and in the winter of 1921-22 the enlarged wing was used in the construction of a trainer which was named *Alexander* by the Weltensegler Company. In collaboration with Fritz Wenk I designed the sailplane *Phoenix* with wing control. In 1923 Fritz Stamer developed the training glider *Bremen*, for which I designed the wing. In the spring of 1923 I built the simplified trainer *Djävlar Annama*, which for the first time proved that the braced monoplane design is satisfactory for training purposes. In 1925 at the Steinmann Company I built a structurally improved version, the training glider *Baby*, which proved very satisfactory, and the sailplane *Hangwind*, a standard design with the aspect ratio of 1:7. A sailplane design for higher performance followed, the *V3*, with an aspect ratio of 1:16 [6]. The last model in this group was the light plane *Liliput*, which was powered by a 7.5 h.p. ILO engine. All these planes were of the high-wing type, except the first version of the *Falke*, which was projected as a low-wing monoplane.

*The numbers in brackets appearing in the text refer to the Bibliography.

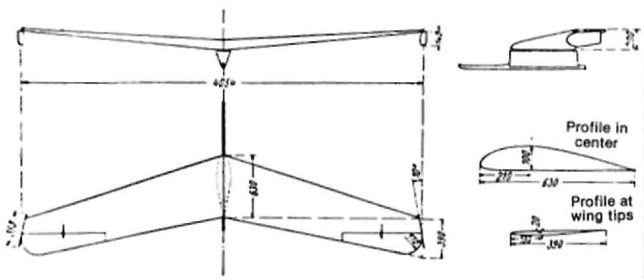
2 Development of High-wing Swept-back Aircraft ("Stork" Types)

TOWARD the end of 1924 the director of the aeronautical department of the German Ministry of Transport, Dr. Brandenburg, initiated the founding of the Rhön-Rossitten-Gesellschaft (RRG). It was to be responsible for organizing soaring contests and supervising the newly created Research Institute on the Wasserkuppe and the gliding schools of both the Wasserkuppe and Rossitten.

The Research Institute consisted of a Meteorological Department and a Department of Aeronautical Technology. I was designated Director of the Aeronautical Department upon recommendation of "Rhönvater" Ursinus. I therefore returned to the Wasserkuppe in the fall of 1925, the year when the Allies' prohibition of the construction of powered airplanes in Germany was at least partially repealed. In addition to working at my regular duties, I was now in a position to begin the systematic development of tailless, and later of Delta, aircraft. In 1926 Prof. Walter Georgii took over the directorship of the Institute, in addition to being head of the Meteorological Department.

Since the financial resources were limited, I chose the method of testing with large free-flying models. I studied the effect of different airfoil sections on the longitudinal stability and the torsional stress of swept-back wings and recorded my findings in a published report [7]. In the course of these experiments we built a model with swept-back wings, one with straight wings, and one in a canard configuration.

The swept-back-wing model *No. 4* (Fig. 8) had type-1 profile distribution, as published in "Results of the Aerodynamics Testing Center in Göttingen," volume 4, by Prandtl-Betz, published by R. Oldenbourg. The wing had hinged end plates set at an outward angle for directional stability. The presentation of this model to the Technical Commission at the Rhön Contest (National Glider Contest) of 1926 led to the appropriation of further



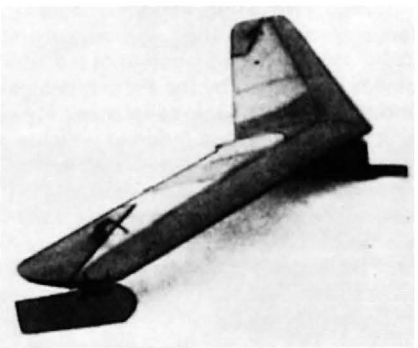


Fig. 8. Swept-back-wing model *No. 4* of the *Stork* series: midwing section, wing-tip section.

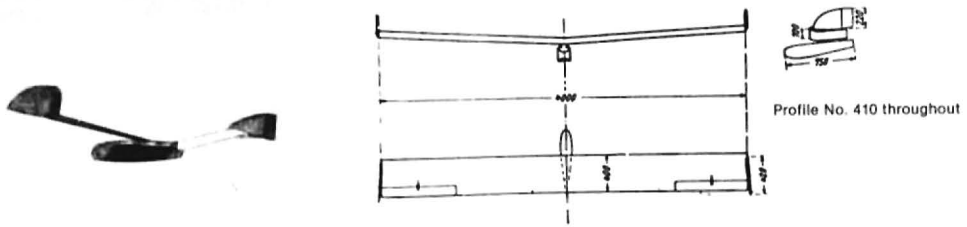


Fig. 9. Model *No. 6* with rectangular wing. Section No. 410 used throughout the wing.

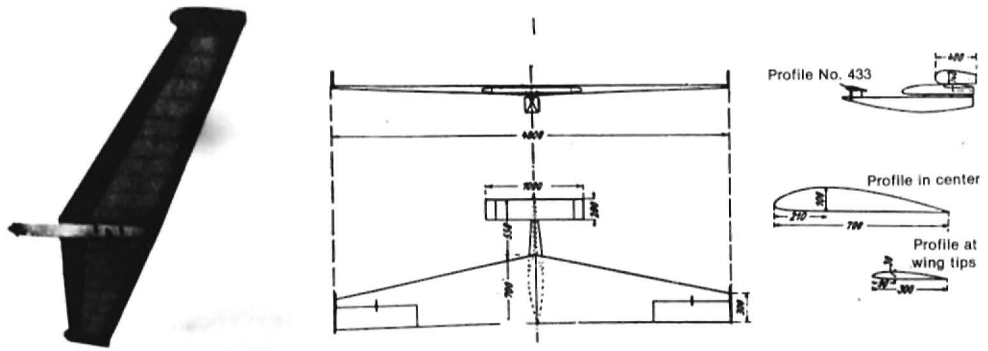


Fig. 10. Model *No. 7*, canard type, flown with and without front control surfaces.

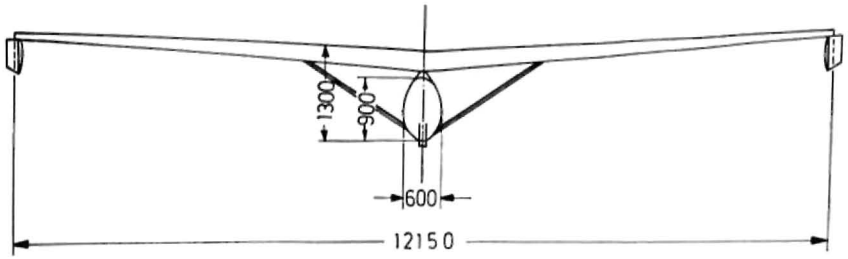
financial support, which gave us the means to develop an experimental full-scale aircraft, later to be named *Stork* [7, 14].

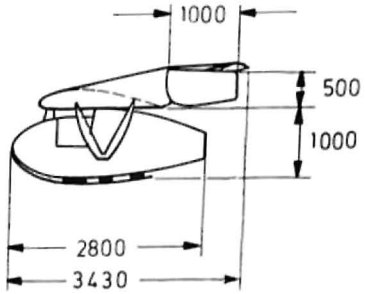
Model *No. 6* (Fig. 9), which had a straight rectangular wing with the symmetrical wing section (Gött. 410), was the precursor of the series of sailplanes developed by the French designer Fauvel and of the *Brett* (Plank) sailplanes developed elsewhere. I devised this inherently stable design in 1926, and reports on this subject were published in both Germany [7] and France [25].

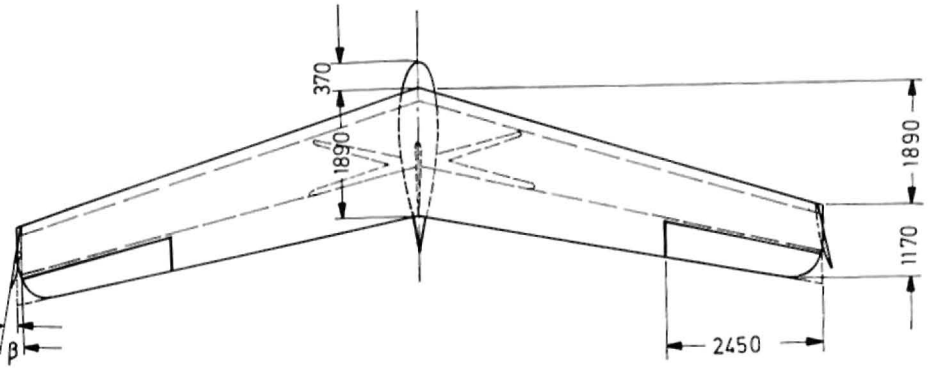
In addition we tested Model *No. 7* in canard design (Fig. 10), i.e., with the elevator located in front of the wing. The wing design with slight sweepback and straight trailing edge became the forerunner of the Delta types which were begun in 1930. Since the elevator was often damaged in testing, we flew the model without the front control surface, which was feasible because the wing had an inherently stable profile distribution. This flying-wing version of the model gave good performance [14].

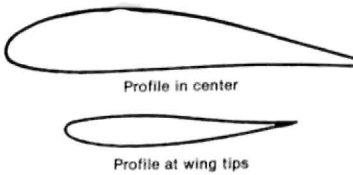
But let us return to the swept-back model. The wind tunnel tests of the type-1 wing section showed low maximum lift values, and we therefore proceeded to change the wing sections. In version 2 we used profiles that were thicker and approaching the Zhukovsky outline. This change resulted in an increase of the maximum lift (see Appendix).

When in 1927 we built the swept-back-wing aircraft *Stork* in the shops of the Research Institute of the RRG on the Wasserkuppe, the wing was based on the above section. Drafting and





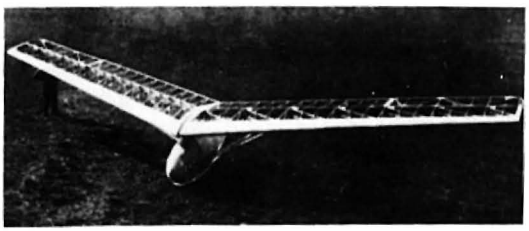




„ STORCH I "

Fig. 11. *Stork I*, experimental glider (1927).

construction of the full-scale *Stork* required working to our fullest capacity, and not until we started the development of the Delta aircraft did we go back to using tests of large free-flying models. The experimental aircraft shown in Figure 11 agreed with the wind tunnel model that had been measured in Göttingen. The wing had two spars and was braced by a V-strut. From the beginning the wing was laid out for additional loads, since the ultimate version was planned to be powered by a light engine. The *Stork* was test-flown by Bubi Nehring in the fall of 1927. The tests primarily showed insufficient directional stability, which also led to poor efficiency of the ailerons. The most favorable position of the end-plate rudders, which originally were hinged pointing downward,



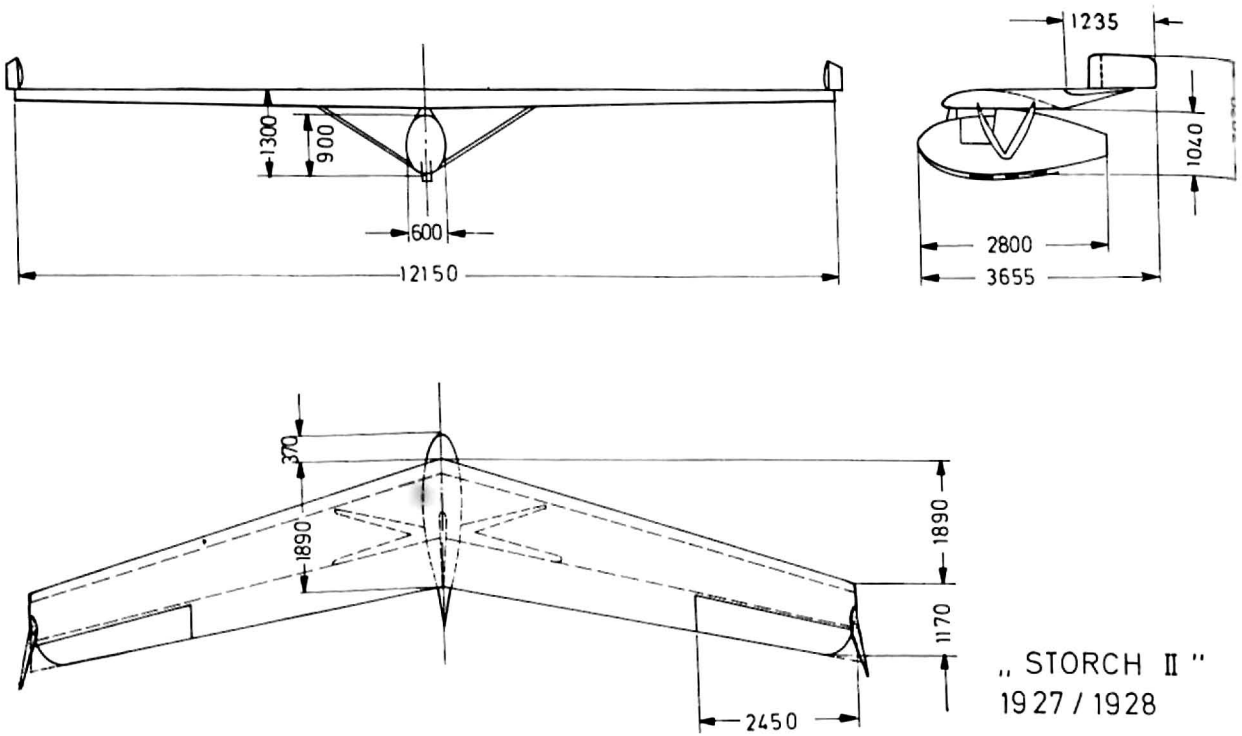


Fig. 12. Experimental glider *Stork II*, without dihedral.

was to be determined by the flight tests. They were left free-swinging, their position to be determined by the airflow around the wing. Therefore these vertical planes could not contribute to the stability around the vertical axis [14].

Since the downward-hanging end plates were often damaged in landing, we moved the rudders to the top surface of the wing. This change made the dihedral of the wing superfluous, since the positive dihedral was intended to compensate for the negative rolling moment caused by the rudders. This version, the *Stork II* (Fig. 12), which was mainly test-flown by Fritz Stamer, still had unacceptable characteristics regarding directional stability and aileron effectiveness [14]. Therefore more changes were needed.

An improved version, the *Stork III*, was obtained by adopting a hexagonal fuselage, which promised better directional stability, and by installing solid end plates with adjustable rudders (Fig. 13). However, the effectiveness of the ailerons was still insufficient. Looking back to the arrangement of the control surfaces on the swept-back wing model, we installed ailerons with top camber, whose rotation axis was at an angle of 90° to the longitudinal axis of the aircraft. To

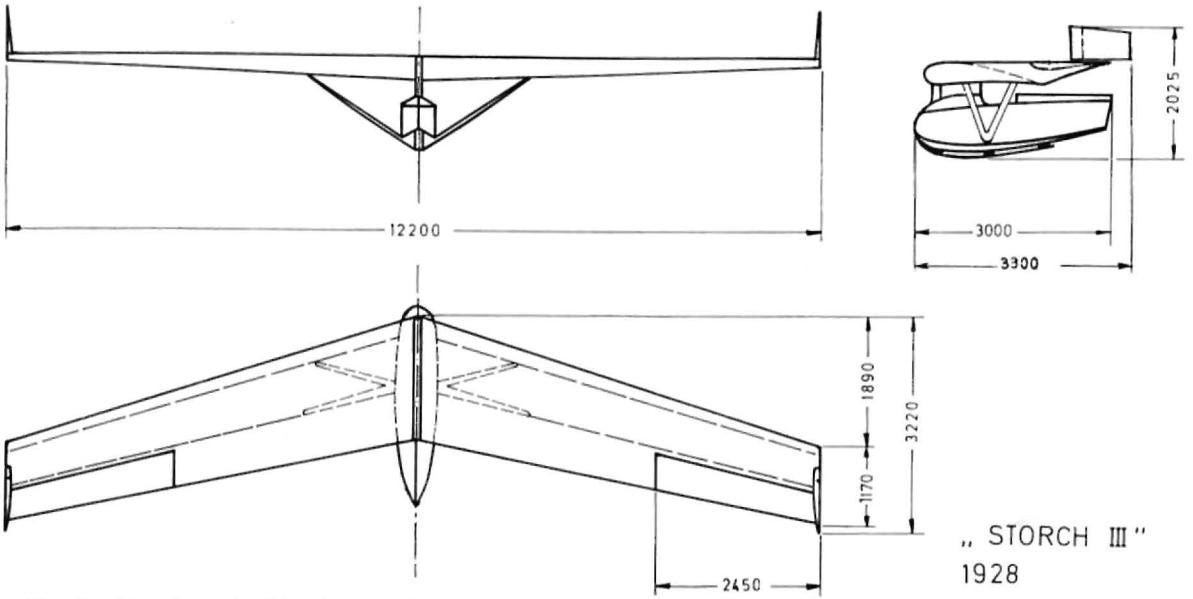


Fig. 13. Experimental glider *Stork III* (fuselage with straight sides).

some extent this aileron arrangement was based on the wing form and cross section of the *Zanonia* seed and the Etrich *Taube*. The Focke-Wulf airplanes also used this type of aileron design. In conversations with Professor Focke and Igo Etrich, the effectiveness of this design of the outer wing sections was confirmed. The test flights, which in 1929 were carried out by our new test pilot, Günther Groenhoff, with the *Stork IV* (Fig. 14), were very impressive. They showed excellent controllability, even in flight attitudes at extremely large angles of attack and at maximum lift. Except for the above changes of the control surfaces, the wing was still the same as in the *Stork I*. The great improvement in flying characteristics achieved by this change in the design of the outer wing is especially remarkable, since on a swept-back wing stalling usually starts in the outer wing areas, which leads to impairment of lateral and longitudinal stability. The *Zanonia*-type design of the wing and the shape of its cross section, however, guarantee dependable controllability even in extreme flying attitudes of the swept-back wing.

Thus the goal set for this development series was reached for the time being [19].

The development of the *Stork* series was still in progress when, in the summer of 1928, Fritz von Opel and the rocket manufacturer Sander came to the Wasserkuppe and asked us to install a rocket in one of our planes, the first attempt of its kind ever to be performed. After a series of tests were run with tailless models fitted with rockets (Fig. 15), long-burning solid rockets were installed in the experimental canard-type aircraft *Ente*. Our flight director, Fritz Stamer, made some success-

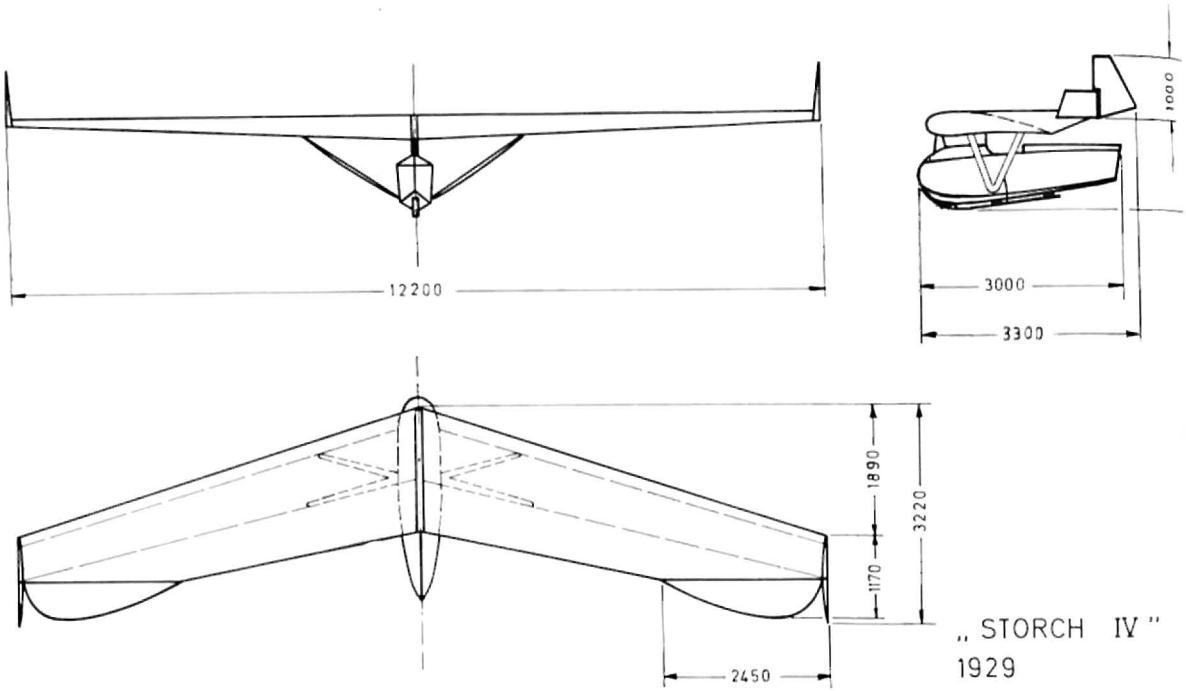


Fig. 14. Experimental glider *Stork IV* (modified aileron-elevators).

ful flights. This was the first time that rockets were used for aircraft propulsion (Fig. 16) [15]. Unfortunately these solid rockets turned out to be quite unpredictable. Nevertheless, on order of Fritz von Opel, we at the RRG started the design and construction of a special swept-back-wing aircraft for further rocket-powered test flights. Disagreements with von Opel put an end to the project, and the experimental rocket aircraft (Fig. 17) was never built. However, the observations of the tests with the rocket-propelled models and aircraft that had been performed led me to research on the basic principles of the dynamics of rocket flight. This work became the basis of later projects of rocket-propelled aircraft.

Toward the end of the summer of 1929 we proceeded to fit the *Stork* with a small engine and to test it with a pusher propeller (Fig. 18). This experimental aircraft, equipped with an 8 PS DKW

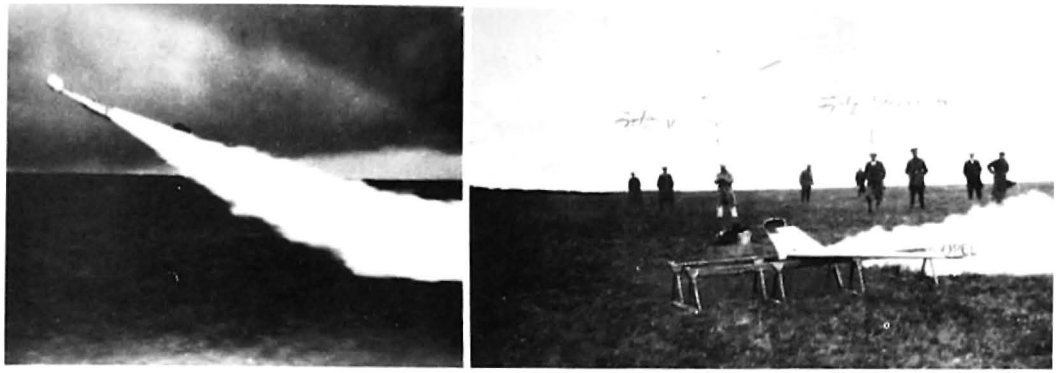


Fig. 15. Model flight with rocket propulsion (*Stork* model with Sander rocket, 1928).

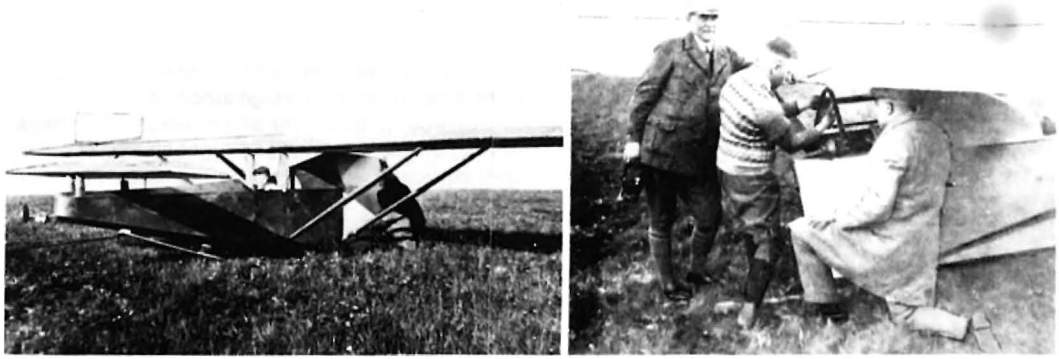


Fig. 16. Preparations for rocket flight with canard: (*Left*) the aircraft; (*Right*) Sander [left] supervising installation of the rocket.

engine, was given the designation *Stork V*. Already in September the first flights were performed by Günther Groenhoff. Flying characteristics and performance proved satisfactory, and we decided to present the aircraft to a larger public [19, 37].

In October 1929 the *Stork V* was demonstrated on the Tempelhof Airfield in Berlin by Günther Groenhoff. The flights were very impressive, but our hopes of obtaining further research grants from government agencies were not fulfilled. But the demonstration inspired the Ullstein publishing house to create the "BZ" prize for the accomplishment of a 300-km overland flight by a tailless aircraft starting on a skid. This prize was specifically aimed at the *Stork*. After our return to the Wasserkuppe, we worked to prepare the *Stork* for a flight of about 2 hours duration by installing larger fuel tanks. Groenhoff made a flight of about 1½ hours, but another problem surfaced. The ailerons, which were aerodynamically so efficient, demanded a constant pulling effort by the pilot. This had not been noticeable during the short-duration test and demonstration flights, but proved very tiring in long-distance flying. To remedy this, we added small trimming surfaces à la Flettner,

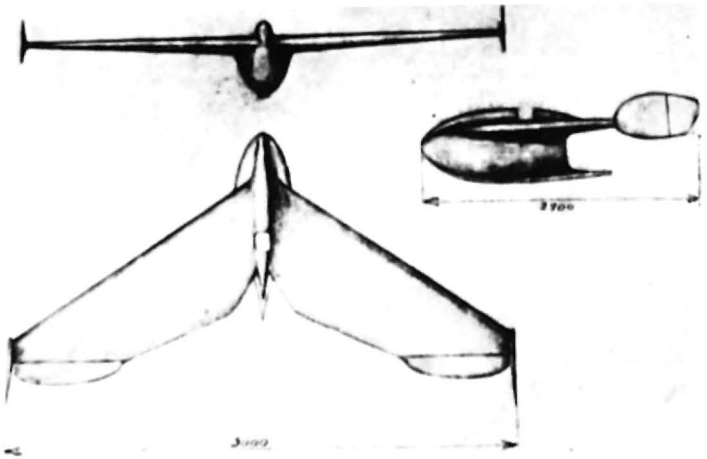


Fig. 17. Design of a rocket-propelled aircraft for Fritz von Opel (1929).

which can actually be seen on some of the photographs (Fig. 18).

In the meantime, transatlantic flyer Capt. Herrmann Köhl had heard of our flights in Berlin and asked us to prepare a demonstration for him in Darmstadt. He was impressed by the all-wing or flying-wing concept projected by Hugo Junkers, especially in regard to achieving long-distance flights across the Atlantic, and he saw in our work a chance to realize such aircraft. It was late in 1929 when the demonstration of the *Stork V* was to take place on the small airfield in Darmstadt. On that day the weather was extremely rough for such a small light craft. We started the test flight in spite of the adverse conditions, and it ended in a crash landing which caused considerable damage to the aircraft. Fortunately the pilot, Günther Groenhoff, was not injured. In spite of this less than perfect demonstration, Köhl decided to award a contract to the RRG for the design and construction of an all-wing aircraft. This was the beginning of a new development series of tailless aircraft which we will describe in the following chapter.

At that time we were working on the design of *Stork VI*, with a considerably larger aspect ratio than its forerunner. This type was built only as a model. When we obtained the order from Captain Köhl, all work on this design stopped.

In order to try for the still available "BZ" prize offered for the first overland flight by a tailless aircraft equipped with skids, Günther Groenhoff had started in 1930 to build a craft using his own funds. This powered glider, *Stork VII* (Fig. 19), which I designed in cooperation with Groenhoff, differed in several ways from its forerunners. It had a cantilever wing (with M-sections with a fixed center of pressure and stressed outer skin), with a larger angle of sweepback in order to improve longitudinal stability. Behind the closed cockpit a 20 h.p. Daimler-Benz aviation engine was installed, which needed an oversize propeller. Since the thrust of this engine proved insufficient, we changed to a 24 h.p. engine. When we finally were able to start the engine by means of a cable winch, it kept stalling during acceleration due to insufficient fuel feeding. Overcoming all these difficulties increased the period of construction to 1¼ years, and earned the aircraft the nickname "Hans Huckebein" ("Johnny Lamefoot"). The term set for the prize was to expire at the end of 1931. Shortly before this deadline Günther Groenhoff started from the Wasserkuppe in very adverse weather conditions. But overcoming

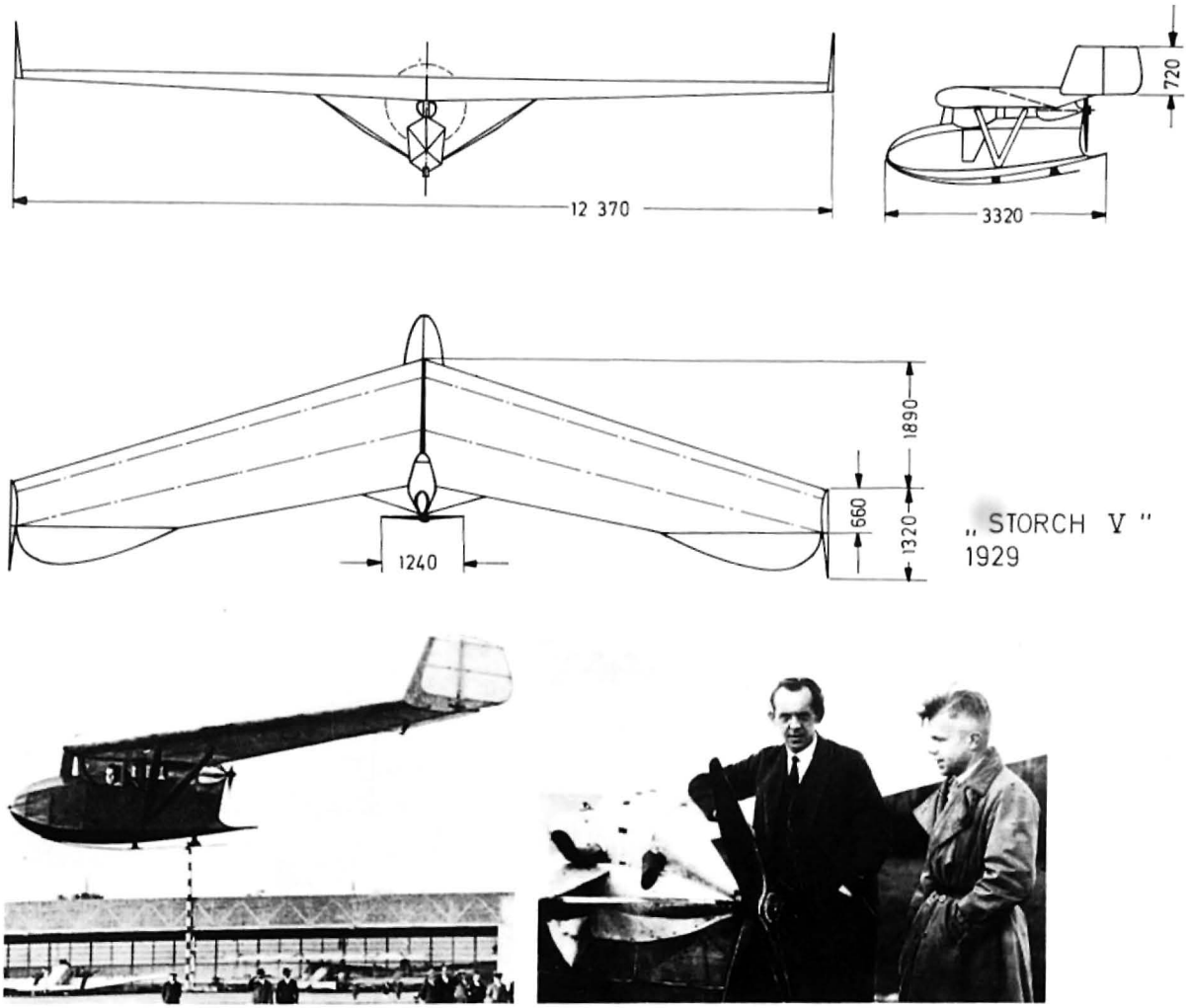


Fig. 18. Experimental aircraft *Stork V:* (*Above*) layout; (*Left*) flight demonstration in Berlin-Tempelhof; (*Right*) Lippisch and Groenhoff with the plane.

all obstacles, Groenhoff successfully reached Berlin in 1 hour and 55 minutes at an average speed of 145 km/h, with an engine of only 24 h.p., thereby winning the prize.

In 1932 E. Philipp in Landsberg/Warthe built the *Stork VIII Marabu* (Fig. 20), which was also privately financed. Compared with the earlier *Storks*, this tailless glider had a larger span and could be flown both tailless or with affixed tail surfaces.

During this period other *Stork*-like types were

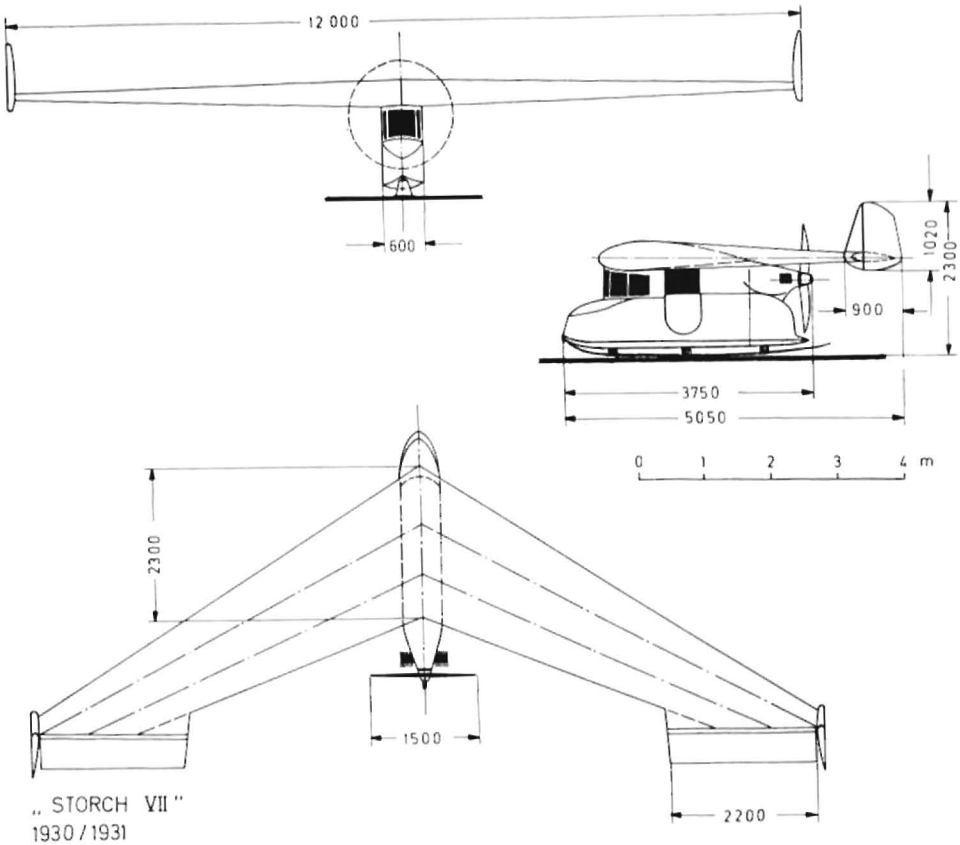
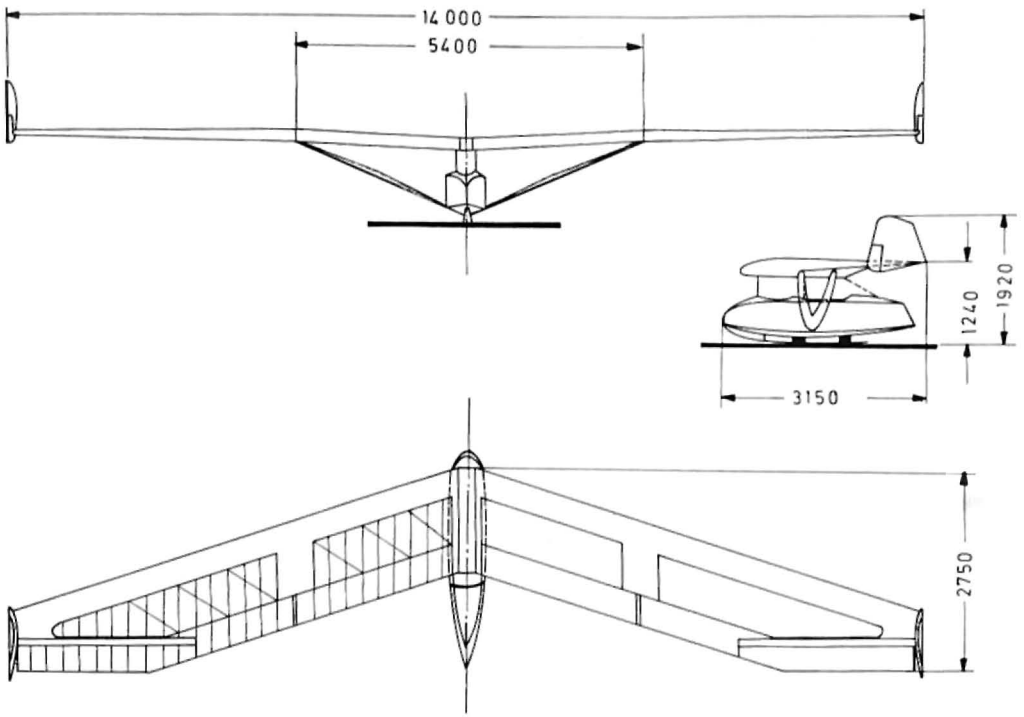


Fig. 19. Light aircraft *Stork VII* (*Hans Huckebein*) built for competition flight (1931).



„ STORCH VIII "
1932

Fig. 20. Tailless glider *Stork VIII-Marabu.* Could also be flown with tail.

built, e.g., the glider by Beyer at the glider school in Rossitten (Fig. 21), and one outside Germany by Professor Hill in England, among others; but I was not personally involved in any of these projects.

The task of the Research Institute of the RRG, however, was not only research but above all to support and develop gliding and soaring flight in a practical way. We were constantly at work designing and constructing more advanced gliders and sailplanes. These aircraft were of normal design and laid out in such a way that they could be copied in the shops of the numerous glider groups which were organized all over the country. Therefore, let me give a short review of the most important gliders and sailplanes I designed during this period.

Fig. 21. Tailless parasol type by Beyer, Rossitten (1932).

The first design, which was completed in 1926, was the training glider R I *Zögling,* in which generations of glider pilots learned their basic flying skills. This type was followed by a second version with a covered cockpit, the well-known R II *Prüfling.* In 1928, after the above mentioned canard-type glider *Ente,* came the sailplane R III *Professor,* which also found favor in countries outside Germany. In the same year, the two-seater *Mannheim* was built according to my plans at Schleicher Aircraft Company, and the construction of the high-performance sailplane *Wien* for Robert Kronfeld was carried out at Kegel Aircraft Company. In 1929 the high-performance two-seater R IV *Rhönadler* followed, also built at Schleicher Aircraft Company. To avoid severe personal injuries in crash landings, the trainer R V *Falke* was designed with a swept-back wing, which made it possible to move the cockpit farther back. This redesign of the *Prüfling* greatly reduced the chance of injury to the pilot. In the following year (1930) we designed the less well-known trainer *Hangwind* and, above all, the high-performance sailplane *Fafnir,* which had trend-setting aerodynamic features.

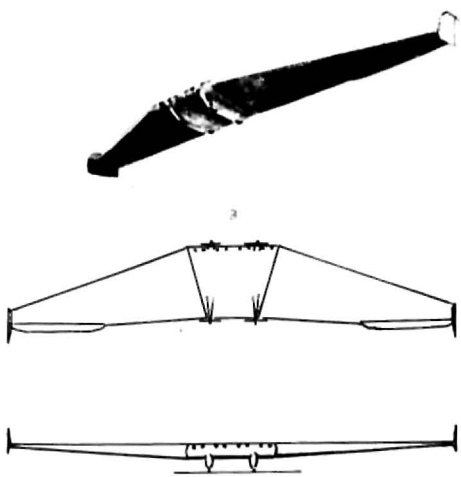
After this short digression let us go back to the tailless aircraft of the RRG, this time to the development of the *Delta* series.

3 Development of the *Delta* Series up to 1933

I had indicated before that the ultimate aim of the development of tailless aircraft was the creation of a pure all-wing craft. We showed such a project drawing at the International Aeronautical Exhibition (ILA) in 1928 (Fig. 22) [31].

However, when we received the order from Captain Köhl, I first designed a low-wing version with a swept-back wing, which was tested as a model (Fig. 23), and is also the basis of the German Patent DRP No. 615 460. But the flying characteristics of that model turned out to be unsatisfactory, and we therefore went back to a swept-back-wing model with a straight trailing edge, which we had tested in the years 1927–28. This design allowed considerable thickness of the midwing section even at great angles of sweepback, and in the full-scale version it would be possible to store all loads inside the wing [28, 31, 56]. A project drawing of such a long-distance commercial aircraft illustrates this concept (Fig. 24). The experimental airplane that was built on the basis of these considerations was given the designation *Delta*, a name which became the general term for this type of aircraft.

Fig. 22. All-wing project by Lippisch, shown in 1928 at ILA.



Again we used the proven development method: starting from the flying model, proceeding to the full-scale glider, and finally to the building of the powered airplane. The use of wind tunnel measurements was not feasible for financial reasons.

Based on the analysis by Birnbaum-Glauert, the aerodynamic theory of wing sections had made great progress in the years preceding the start of our project. It had become possible to calculate the outline of profiles that had no displacement of the center of pressure, and we were able to base the wing design of the *Delta* on this method. The members of the team working on the development of the first *Delta* were the following: Hans Jacobs, Fritz Kraemer, Wilhelm (Bill) Hubert, Beverly Shenstone, Heinrich Voepel, and the pilot, Günther Groenhoff. Beverly Shenstone, the Canadian who worked with us as a volunteer because of his interest in the project, had introduced us to Glauert's methods of calculation, which he had learned in England.

In 1930, after the flight tests of the large model (Fig. 25) had been completed with good results, we started the construction of the glider *Delta* (Fig. 26) in the shops of the RRG. The wing

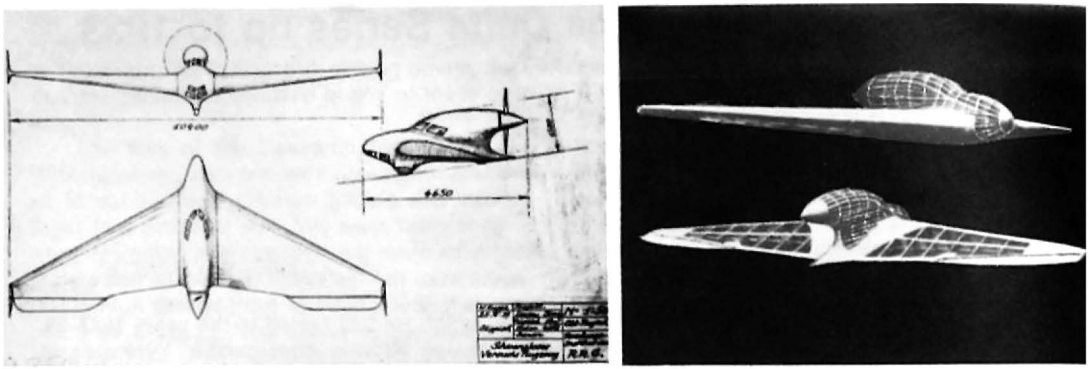


Fig. 23. First *Delta* project for Köhl: (*Left*) layout; (*Right*) two views of the flying model before covering.

was set in midposition, and we followed a construction method that was similar to the one used in the building of sailplanes. A strong main spar formed a solid combination with the plywood-covered forward portion of the wing, assuring high transverse and torsional strength. The narrow rear spar served only for the attachment of the elevator and aileron flaps. As opposed to the swept-back wing, the Delta wing could be fitted with separate elevator and aileron control surfaces. The inboard pair served as elevators, and the outboard pair as ailerons. In addition, the ailerons could be used for trimming the elevator control surfaces, and the elevators for adjusting lateral control. The diagram of the control cables is represented in Figure 26. The glider was completed in the summer of 1930, and the test flights were carried out by Günther Groenhoff during the Rhön Soaring Contest. The flying characteristics proved satisfactory, but landing on the short

Fig. 24. Project drawing for a long-distance commercial Delta aircraft.

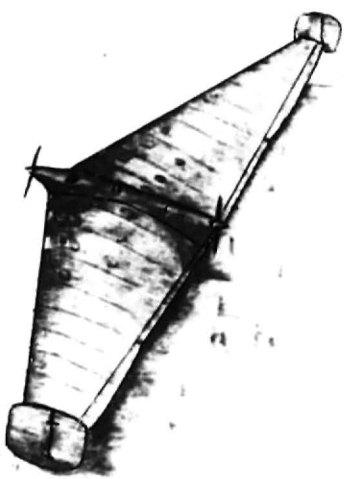
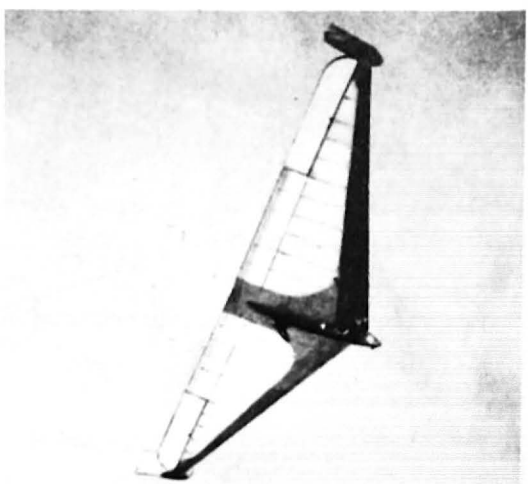
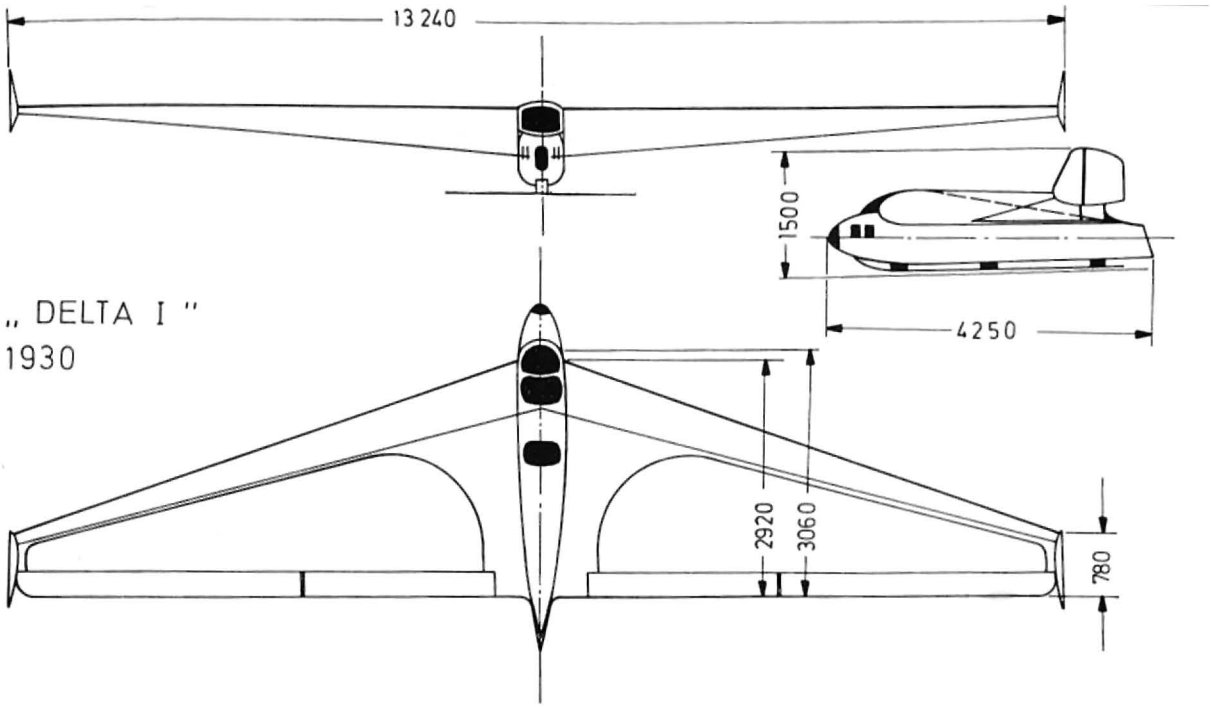
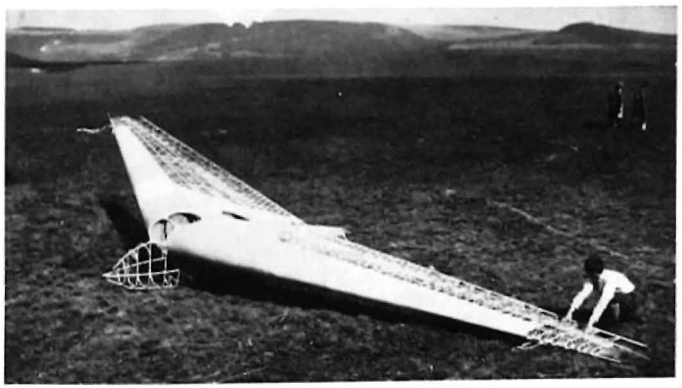


Fig. 25. Large flying model for *Delta I* (1929).







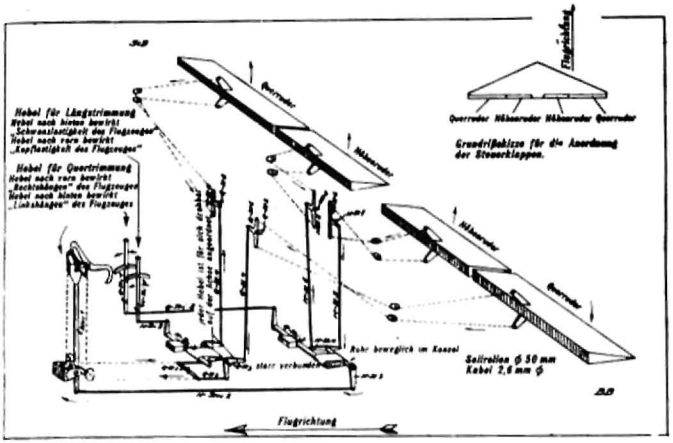


Fig. 26. Glider *Delta I:* (*Above*) layout; (*Left*) during construction; (*Right*) in flight; (*Below left*) control diagram.

rounded skid was difficult. The glider would start bouncing, and these shocks caused undue stress to the structure. After a few relatively short starts, which included a soaring flight, Captain Köhl and I decided to equip the glider with a light engine. To insure good propeller efficiency we chose a low-wing arrangement with a pusher propeller.

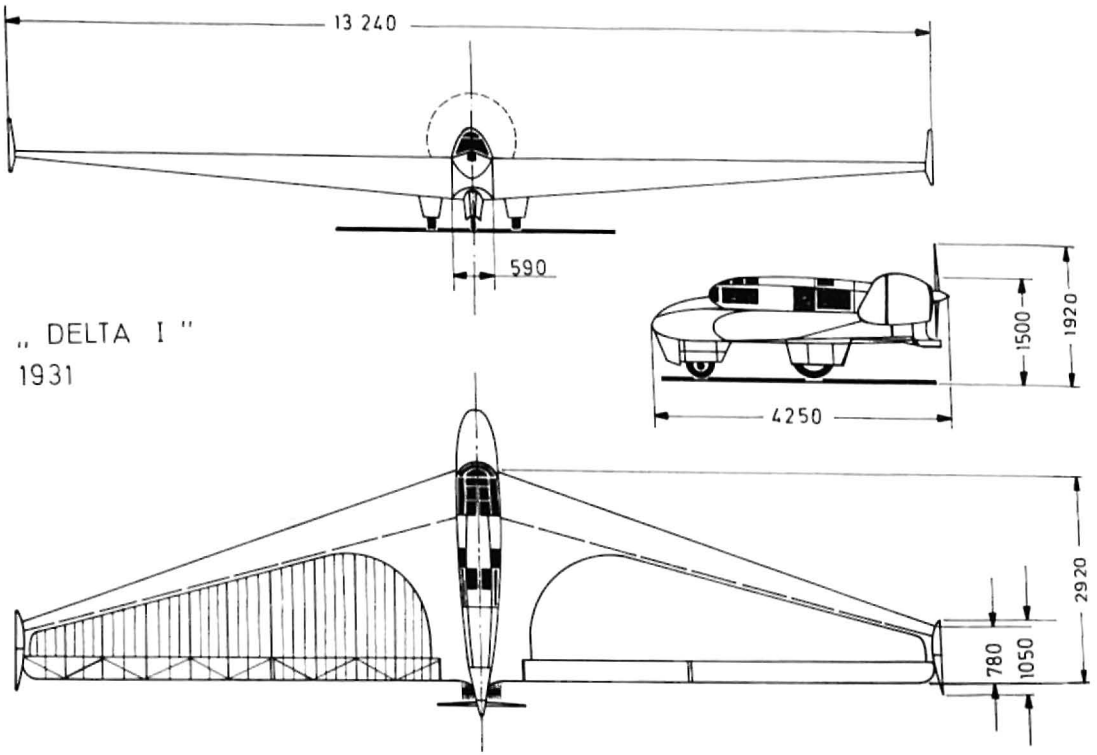


Fig. 27a. *Delta I* (1931), layout.

We used a three-wheel undercarriage, which at that time was quite unusual. Captain Köhl had obtained a 30 h.p. Bristol-Cherub engine, which Director Croneiss had put at his disposal. The wing and the control surfaces of the *Delta* remained unchanged; only the fuselage and the undercarriage were rebuilt.

The powered *Delta I* (Fig. 27) was test-flown on Whitsunday in June 1931 on the Wasserkuppe. The grass had already grown high, and takeoff was difficult with the small engine. We therefore placed a slanted beam at a distance ahead of the plane, which gave the front wheel a push upward, increasing the angle of attack of the airplane and therefore facilitating takeoff. Performance and flying characteristics were very satisfactory. Groenhoff flew the plane in all possible attitudes, even performing loops and other aerobatic maneuvers. The wing dimensions of the *Delta* were as follows:

Wingspan	13.24 m
Chord of wing at midsection	3.00 m
Thickness at midsection	0.60 m
Wing tip chord	0.90 m
Thickness at wing tip	0.10 m
Wing area	25.80 m²
Aspect ratio	6.8

Again we decided to present this first all-wing aircraft to the public at Berlin-Tempelhof [28, 31, 37]. On the flight to Berlin engine trouble developed, and during the landing at the Tempelhof Airfield the engine stalled completely. On closer inspection we found that the crankshaft bearing was burned out due to overheating. Since immediate

Fig. 27b. *Delta I* during flight demonstration at Berlin-Tempelhof.

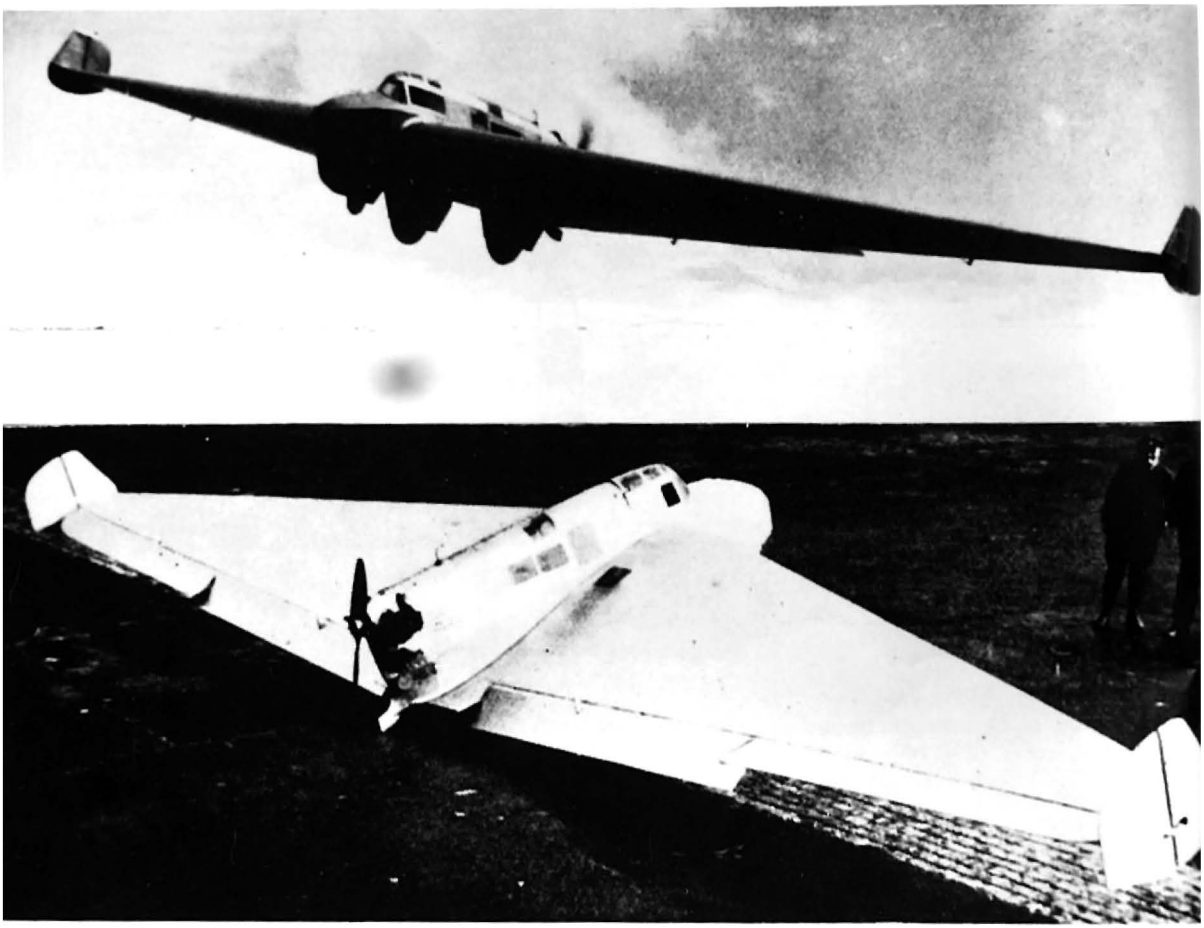
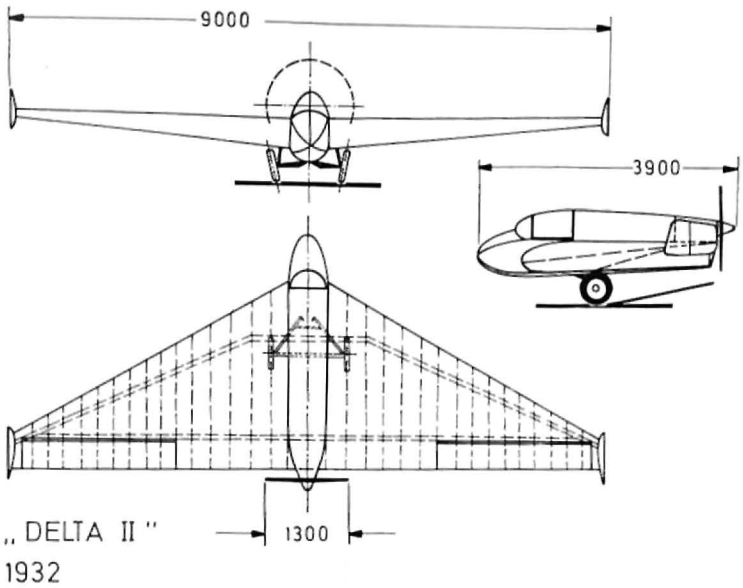


Fig. 27c. Two views of *Delta I.*

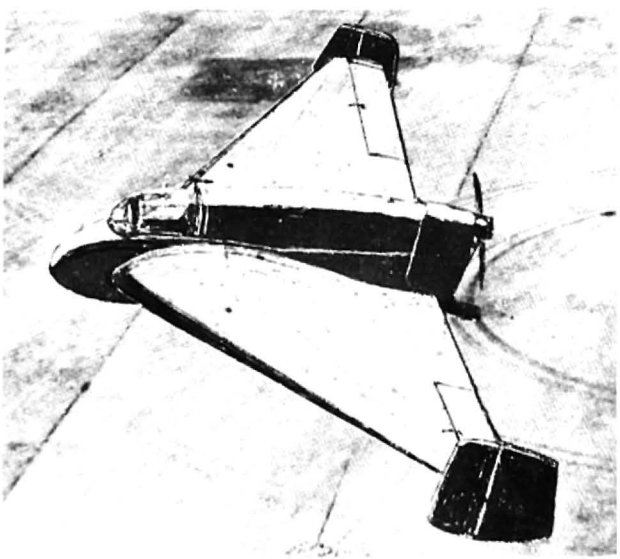


repair was impossible, Director Croneiss gave us a second Bristol-Cherub engine, which was installed for the demonstration at the Tempelhof Airfield on September 25, 1931. Günther Groenhoff flew the *Delta* in all flight attitudes and even forced it into a spin. Groenhoff thus proved the effectiveness of the Delta-type aircraft, but in spite of the successful performance adequate financial support was not forthcoming.

While the *Delta I* was still stationed at Tempelhof, Captain Köhl started on a test flight which almost ended in a serious accident. The *Delta* started bouncing during takeoff, and at the first impact on the runway the nosewheel of the three-wheel undercarriage broke off. However, Köhl succeeded in regaining control and went on an extended flight without being aware of the damage. On his return over the airfield we tried to communicate by gestures to him what had happened, holding up the broken-off nosewheel. He understood, and on the second attempt succeeded in landing safely on the rear part of the undercarriage and the tail skid.

As I mentioned before, the control surfaces

Fig. 28. *Delta II* for G. Groenhoff (1932).



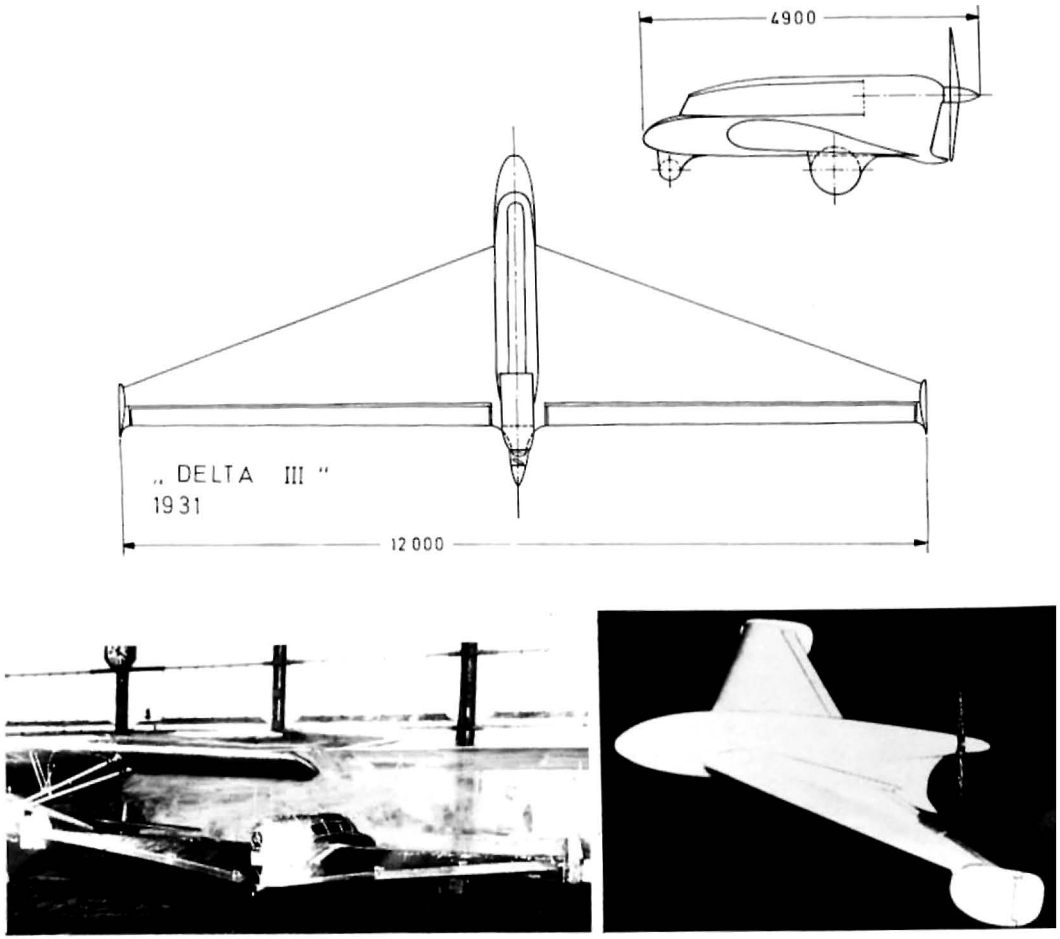


Fig. 29. First version of *Delta III:* (*Above*) layout; (*Left*) view of the aircraft; (*Right*) model built in the course of the design work.

were installed on the straight trailing edge of the Delta wing. During most of the flight the aerodynamic forces generated a moment on the control surfaces. This worked against lateral and longitudinal stability and demanded constant exertion by the pilot to counteract these forces, which on long flights proved very tiring. To correct this effect we installed the control flaps like auxiliary wings with inverted camber, leaving a vertical slot between the main wing and the controls. In addition, the control surfaces were given an inverted wing profile and were activated around a rotation axis located above the profile. We ordered some wind tunnel measurements on profiles with extreme camber which were stabilized by this type of control surfaces. The results confirmed the accuracy of our method. All subsequent Delta types were fitted with this type of controls. The *Me 163,* which will be discussed later, had such an arrangement of control surfaces—although special-

ly adapted—which was very effective, both regarding its aerodynamic characteristics and the balance of control moments.

In the meantime, we had started the construction of a small single-seater, the *Delta II* (Fig. 28), which was adapted especially to Groenhoff's measurements. We chose the light (24 h.p.) engine which had been developed by Ursinus. Unfortunately the troubles arising with this still untested engine made it impossible for us to get the aircraft into the air on the Wasserkuppe.

Belatedly the Air Ministry decided to award us a contract for an experimental Delta airplane on the basis of our demonstration of the *Delta I* in Berlin. In order to obtain this contract, however, we had to comply with certain conditions. The airplane was to be built at the Focke-Wulf Aircraft Company in Bremen, a long way from the Wasserkuppe, where the drawings had to be done by our small staff according to norms demanded in industry. The design was conceived as a one-engine experimental aircraft with a pusher propeller, and was named *Delta III* (Fig. 29). Unfortunately, the complicated procedure we had to follow caused long delays in bringing the construction to completion.

In the course of the year 1932 we also worked on a number of Delta projects for long-range carriers. There were two projects for two-engine transport planes, one with water-cooled, in-line engines (Fig. 30), the other with air-cooled, radial engines (Fig. 31), and a project for a commercial airplane with five, 130 h.p., in-line engines (Fig. 32), which was inspired by Director Hammer of the South American Condor Airline. All these designs were built as demonstration models only [31, 56].

In the same year we tried to obtain a contract from the Ministry of Defense for the development of a Delta-type bomber. I was given to understand, however, that there was no interest in a low-wing monoplane design but that possibly a high-wing aircraft like the Stork types might have a future.

The year 1932 was fraught with tragic events and critical setbacks. At the Rhön Soaring Contest—the thirteenth—Groenhoff suffered a fatal accident in the high-performance sailplane *Fafnir*, and Kronfeld's *Austria* disintegrated in a cloud, while Kronfeld himself barely escaped with his

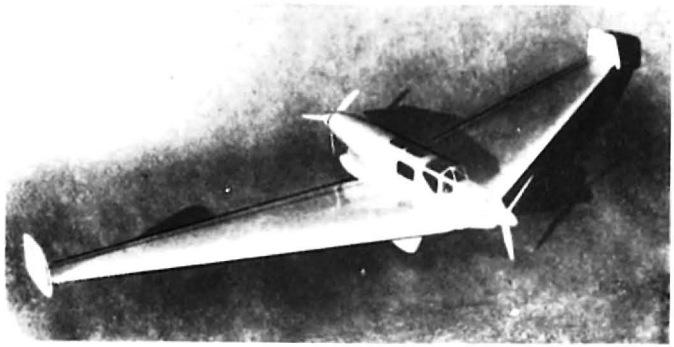
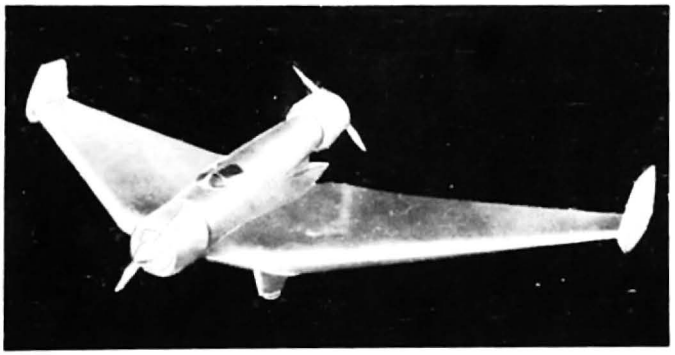


Fig. 30. Model of a project for a mail carrier.

Fig. 31. Model for a military aircraft (1932).



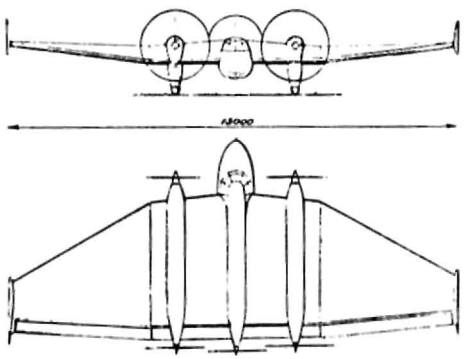
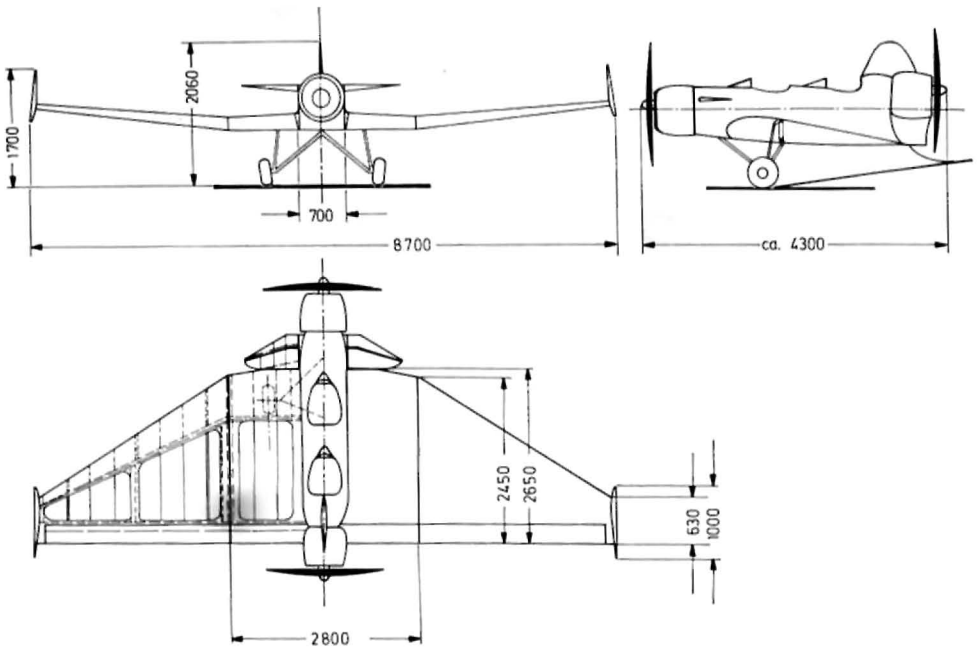


Fig. 32. Layout of a project of a 5-engine transport plane (1932).



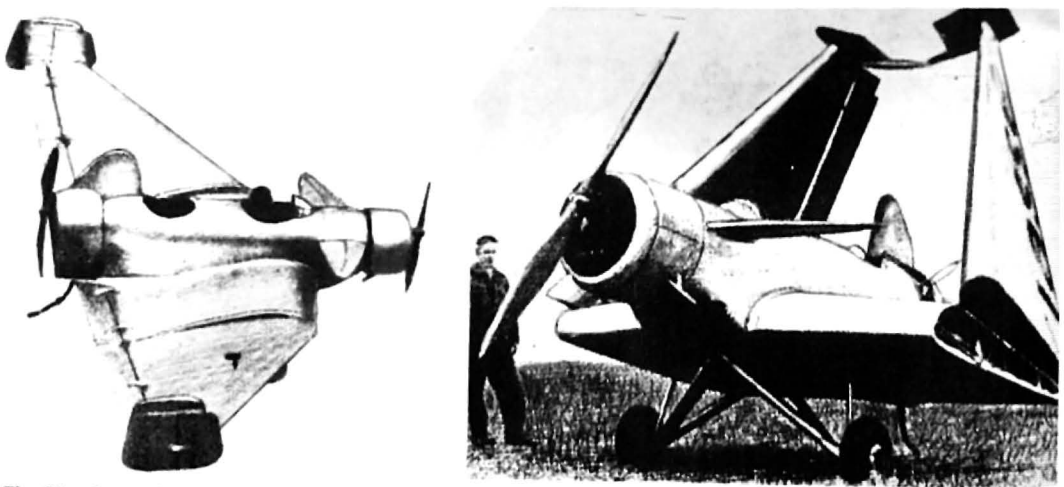


Fig. 33. Sport plane *Delta IV*—Fieseler *F3 Wasp* with folding wings (1932).

life. Furthermore, an unfortunate disagreement arose between Captain Köhl and the RRG. While apparently in a despondent mood, Köhl had given an interview to the press which contained unjustified statements and charges against us. This interview was published, and a dispute ensued that went past the point of reconciliation. In the end, the RRG took over the *Delta I* and repaid the funds that Captain Köhl had invested.

We received only one order from private industry. It came from the Fieseler Aircraft Company in Kassel, who wanted a sport plane with folding wings which they intended to enter in the European Rally taking place that same year. This airplane, the *Delta IV-F3 Wasp,* which was hastily designed, did not measure up to the requirements (Fig. 33). In the fall of 1932 Fieseler had to terminate test flights. I had installed small elevators in front of the midwing section of this airplane in order to guarantee a shorter takeoff. At the same time, these winglets retarded stalling of the midsection of the wing. This in turn caused stalling of the narrow outer wing sections at smaller angles of attack, and led to instability of the airplane. There appeared a forward displacement of the center of pressure, making the airplane dangerously tail-heavy. In the range of maximum lift, the controls were not sufficiently effective to compensate for this shift, and at the end of the test flight the airplane was seriously damaged in landing [37, 56].

Director Ernst Heinkel of the Heinkel Aircraft Company had also attended the demonstration of the *Delta I* at Berlin-Tempelhof and some time later arranged a meeting in Warnemünde to discuss the possible development of a Delta-type airplane. However, under the influence of his chief designers, the Günter brothers, Heinkel abandoned the plan. In order to maintain some connection with the RRG, the Heinkel Company ordered a preliminary study of a tailless airplane for reconnaissance which would offer an unencumbered rear view. In 1932-33 we tested a large flying model built to these specifications (Fig. 34). At the same time we carried out theoretical studies of flow interference on the wings. The projected aircraft was to have a swept-back wing topped by a straight wing. We achieved several satisfactory flights [37], but did not receive a contract for further development.

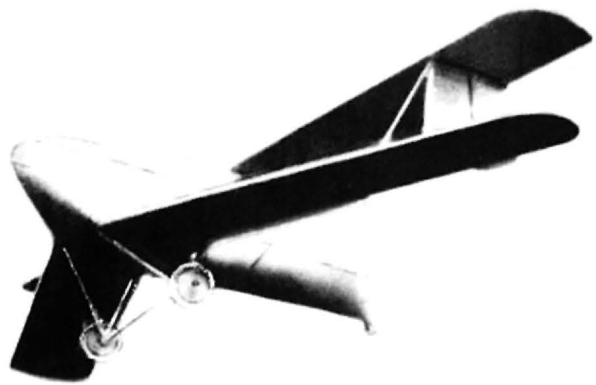


Fig. 34. Tailless biplane model for Heinkel (1932).

As 1933 dawned, the political and economic situation in Germany had become so critical that our problems with the new Delta types were greatly overshadowed by historical events. Changes were in the making that would also affect our work.

4 Work at the German Research Institute for Soaring Flight (DFS)

IN 1933, after the transfer of power and in the course of the new "alignment" policy, the survival of the RRG looked questionable. Finally it was decided to subordinate the Institute to the Deutscher Luftsportverband (DLV—German Airsport Association). The RRG was renamed Deutsche Forschungsanstalt für Segelflug (DFS—German Research Institute for Soaring Flight) and moved to a small airfield in Darmstadt-Griesheim, where the Department for Powered Flight of the RRG had been located since 1925. The gliding school and the facilities for special research projects stayed on the Wasserkuppe.

Since the DLV soon tried to exert influence on the scientific research of the DFS in addition to exercising its administrative duties, work became more and more difficult. Dr. Adolf Baeumker, Director of the Department of Research at the Air Ministry in Berlin, recognized this problem and we are indebted to him for using his influence to obtain the separation of the DFS from the DLV and incorporating it into the net of research institutes administered by his department.

I returned to the design of high-wing swept-back aircraft for essentially two reasons: first, the above mentioned rejection of the low-wing monoplane design by the Heereswaffenamt (Department of the Army); second, the death of Günther Groenhoff at the Rhön Contest. In Groenhoff we had lost the experienced and highly gifted test pilot of the swept-back and Delta airplanes. Our plan to entrust the testing to an outstanding glider pilot failed when the pilot, Deutschmann, suffered a severe injury. "Bill" Hubert took over the test flights for the rebuilt *Delta I* and the *Delta III* which had finally been completed in Bremen. He too suffered a crash, fortunately a less severe one. When Hubert tried to take off without the motor cowling, he found that directional stability was seriously impaired. The airplane started to drift and Hubert injured his foot in the crash landing. The powers-that-be decreed that because an engine located to the rear of the pilot presented grave danger to the pilot in such situations, the engine must be immediately moved to the head of the fuselage and had to be supplied with adequate cowling. All further test flights were forbidden. Therefore I concluded that first of all we needed an easy-to-handle tailless training plane for the instruction of pilots before we could continue the development of swept-back and Delta-type aircraft.

This decision led to the construction of the tailless trainer *Stork IX* (Fig. 35). This was a high-wing design with struts and an open cockpit. It was controlled by means of a hanging control stick. The two-spar wing had a profile with a stable center of pressure, which remained unchanged along the wingspan except for the outer wing portion and the combined elevator and aileron control flaps. This tailless training glider was flown by different pilots and did not present any unusual difficulties.

Another version featuring a closed cockpit, the *Stork IXa* (Fig. 36), was built in Darmstadt-Griesheim and was tested by Wiegmeyer [37]. This glider also showed good flying characteristics and performance.

I therefore decided to build a motorized experimental aircraft using the wing of the *Stork IX*,

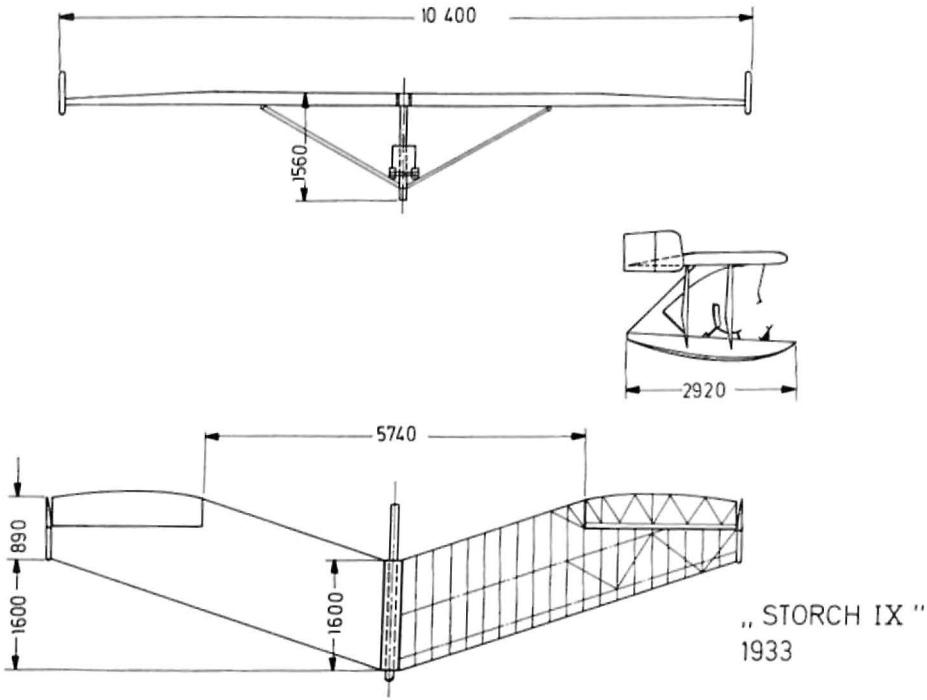
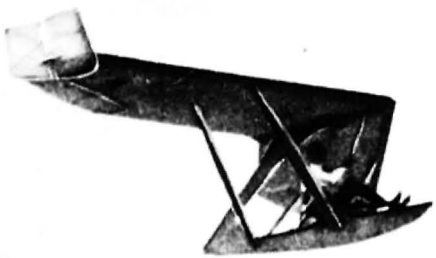


Fig. 35. Tailless glider trainer *Stork IX*. Layout and view in flight.

which had already been tested, and the 30-h.p., Bristol-Cherub engine which had been used in the *Delta I*. This airplane, the *Stork IXb* (Fig. 37), was built on the Wasserkuppe in 1933 but was not test-flown until 1934 in Darmstadt by our pilot Wiegmeyer [37]. Since the directional stability was not yet sufficient, we modified the fuselage. Later we replaced the rebuilt wooden fuselage with one constructed from welded steel tubing (Fig. 38). A series of tests with different end plates led to the conclusion that end plates with the rudders installed below the wing tips produced the best stability and controllability.

In spite of the political upheaval of the preceding two years we had been productive in the design and construction of new soaring planes of conventional design. In 1933 and 1934 we built



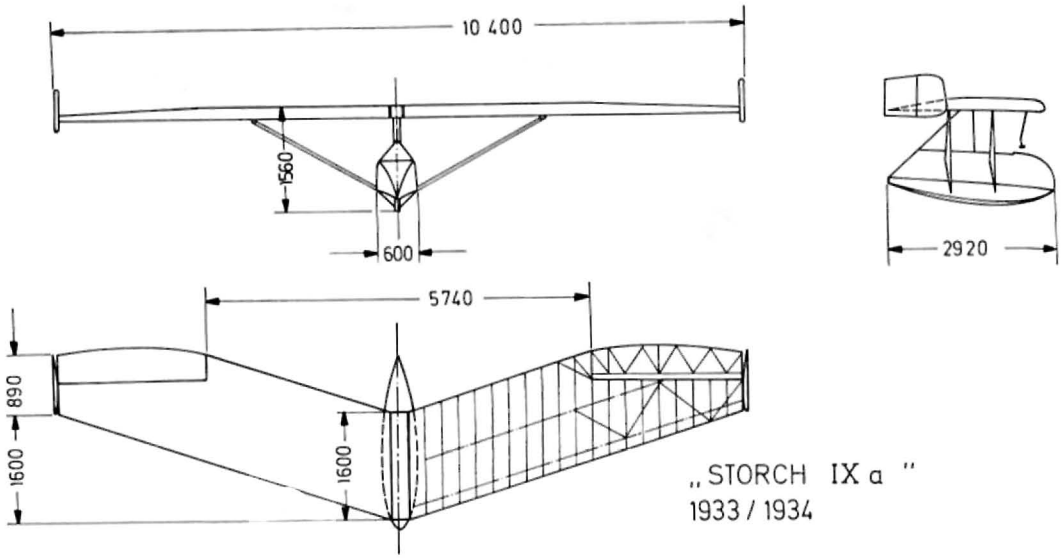


Fig. 36. Tailless trainer *Stork IXa* with covered fuselage (1933). Layout and view in flight.

and tested the single-place, high-performance sailplane *President;* a large two-place research sailplane, the *Urubu Obs* (Observatory), of 26 m wingspan; and a powered glider, *Maikäfer* (June Bug), with an 18-h.p., Köller engine. The crowning achievement of this series was the single-place high-performance sailplane *Fafnir II–São Paulo, a* refined version of the successful *Fafnir I.* In 1934 Heini Dittmar achieved several world records with the *Fafnir II,* among them a distance flight of 375 km, which was mainly due to the Fafnir's gliding angle of 1:30, a phenomenal one for its time. This was the last airplane of conventional design that I was to build, since the Aerotechnical Department was divided into two new departments, the All-wing (Flying-wing) Department, which remained under my direction, and the Sailplane Department, which was managed by my proven co-worker, Hans Jacobs. It would not have been possible to accomplish all the work in any other way. But let us go back to the story of the tailless aircraft.

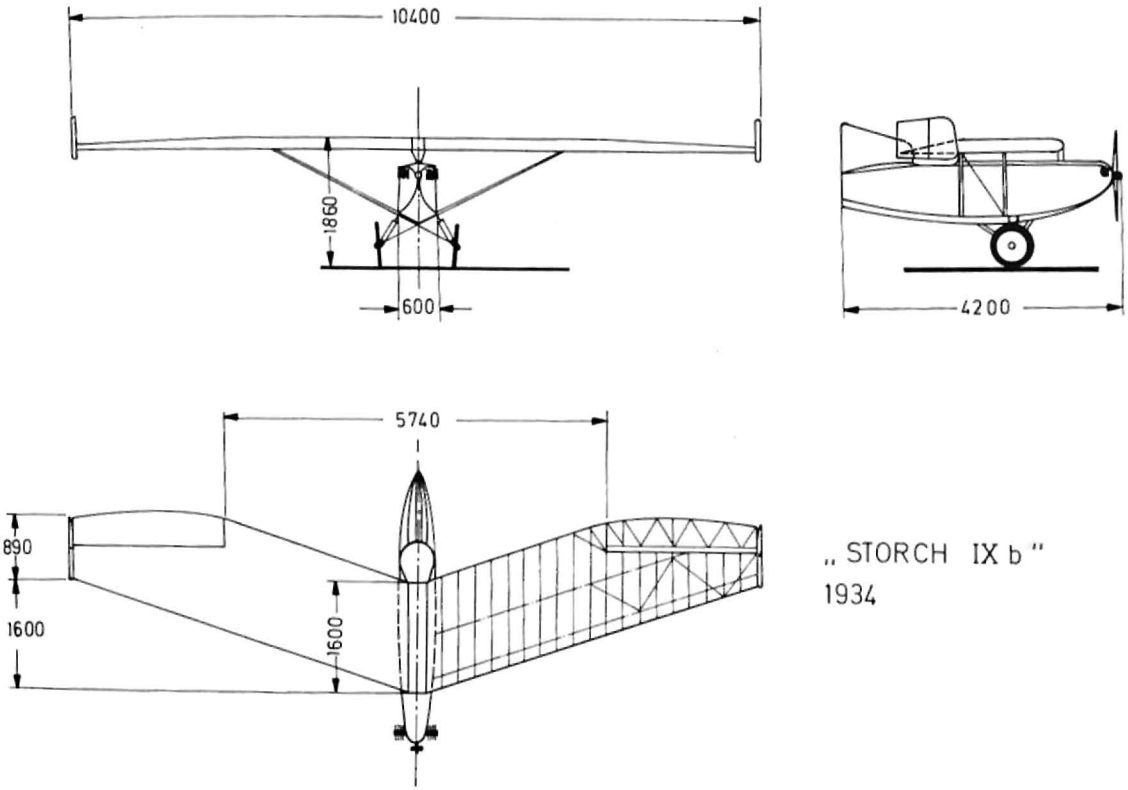


Fig. 37. Light plane *Stork IXb* (1933-34).

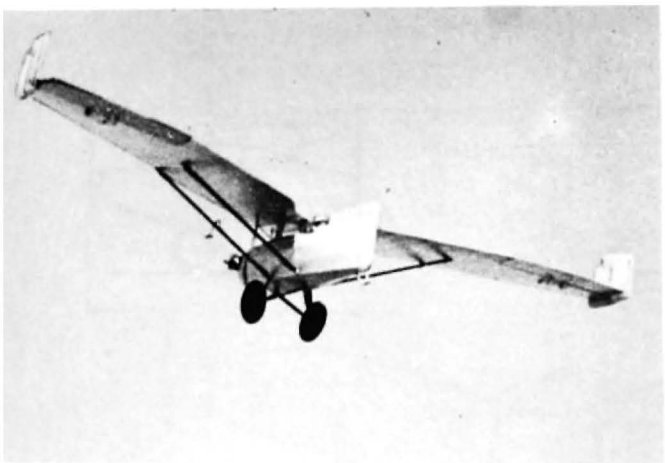
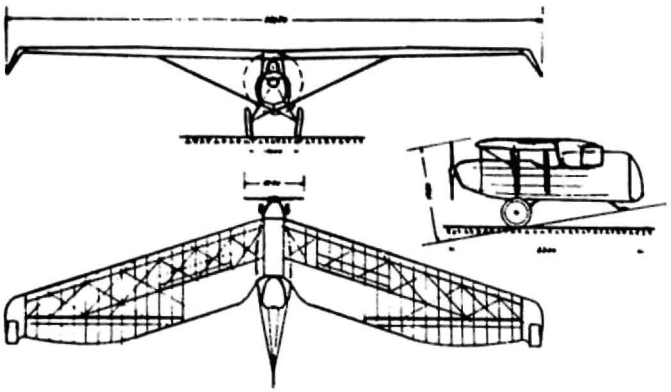


Fig. 38. *Stork IXb* with new fuselage in steel tube construction (1937).

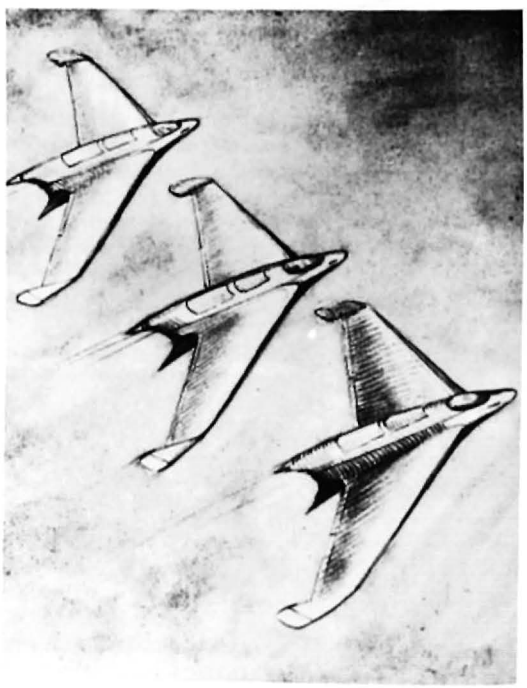
Fig. 39. Project *Stork IXc* with enlarged wingspan.



Following an invitation by Colonel Dinort in December 1934 I had given a talk to the Richthofen squadron at the Air Base Döberitz near Berlin on the mlitary application of tailless and Delta aircraft. At this presentation I showed an illustration of a low-wing monoplane Delta fighter squadron (Fig. 40) and the project drawing of a high-wing reconnaissance plane. The drawing of the Delta squadron survived and is characteristic of the advanced concept of high-performance aircraft at that time. Except for some tests with powered flying models, none of these designs was brought to realization.

In the meantime the *Delta III*, under the direction of Fritz Kraemer, had been modified by changing the pusher engine to a tractor engine. The work was carried out in Darmstadt-Griesheim (Fig. 41). The plane was test-flown by Wiegmeyer. Numerous test flights were completed and the characteristics of the plane were recorded. The *Delta III* was finally officially licensed with the designation D-ELTA. Unfortunately it crashed on a ferry flight to the Federal Air Testing Center at Rechlin. After a stop at the Siebel Company in Halle-Saale, Wiegmeyer had attempted an air show takeoff [37, 56]. The failure of the *Delta IV-F3 Wasp* and the crash of the *Delta III* almost put

Fig. 40. Project of a one-seat Delta fighter (1934). Drawing by Lippisch.



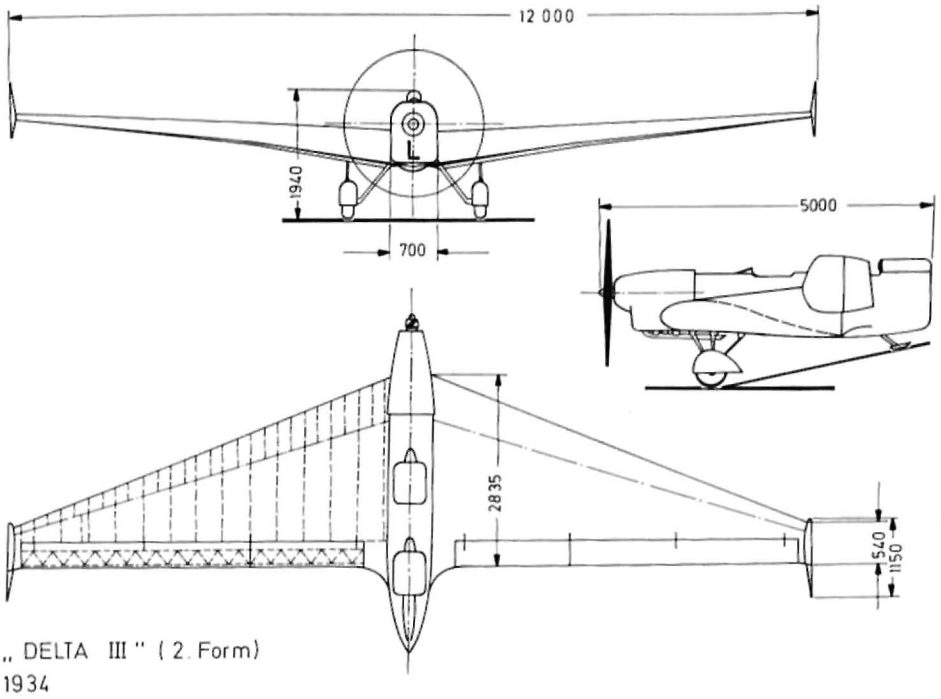
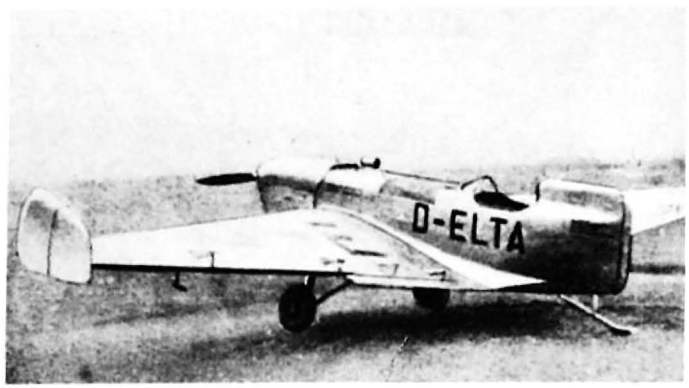


Fig. 41. *Delta III* after modification (engine moved to front).

an end to the development of Delta aircraft. It is due to the successful efforts of Professor Georgii that in spite of the disastrous events further funds were obtained from the Air Ministry for rebuilding the crashed *Delta IV*.

The DFS took over the airplane from the Fieseler Company. The pusher engine was taken out and the additional elevator surfaces were removed, which led to the creation of the *Delta IVa* (Fig. 42). Wiegmeyer was again entrusted with the testing. During landing after a high-altitude flight with a large specially designed propeller, a sport plane crossed his landing path. In order to prevent a collision he accelerated again. The wing, which was already in landing position, stalled, the plane rolled over on its back, and was completely destroyed. Wiegmeyer fortunately remained uninjured. Shortly thereafter he left the DFS and joined the Flugfunk-Forschungsinstitut (FFD—Research Institute for Flight Electronics) in Oberpfaffenhofen, where he was killed when the *Ju 52* he was flying crashed from unknown causes. Because of the accident of the *Delta IVa*, all work on



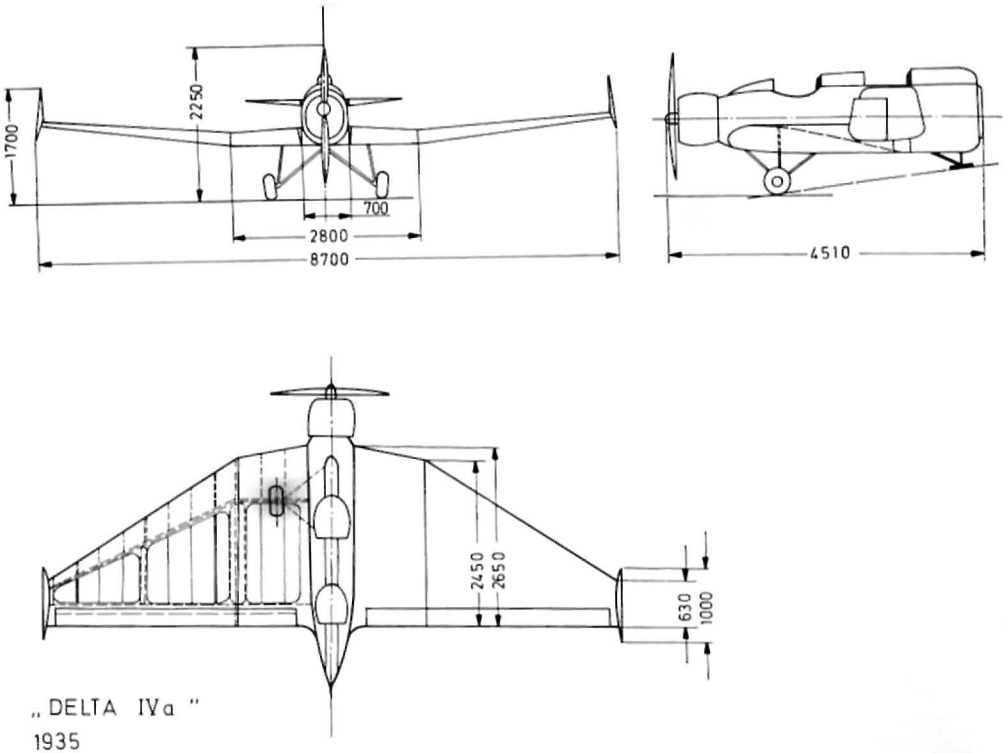
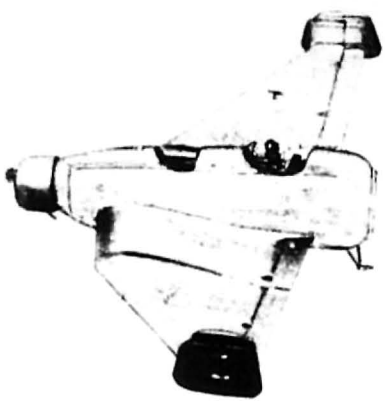


Fig. 42. *Delta IVa*—modified one-engine version (1935).



the development of Delta aircraft was to be discontinued in accord with a decision of the Technical Commission composed of representatives of the Deutsche Versuchsanstalt für Luftfahrt (DVL—German Institute of Aeronautical Research) and the Technical Department of the Reichsluftfahrtministerium (RLM—German Air Ministry). The commission's conclusion read: "The Delta type shows no promise and there is no prospect that this type of design will lead to a practical, serviceable aircraft." However, in spite of the negative decision of the commission, Professor Georgii's efforts on behalf of the Delta succeeded, and we obtained a small grant for the continuation of our work.

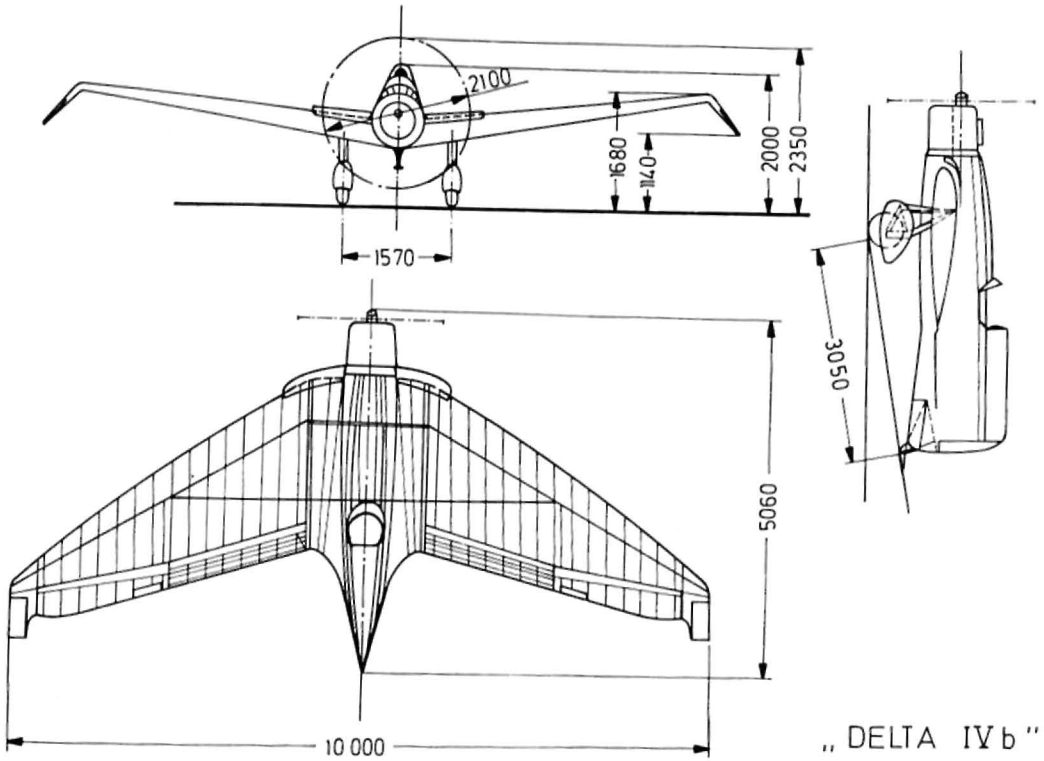


Fig. 43. *Delta IVb* with new wing (1936).

In rebuilding the *Delta IVa* we made a number of basic changes. The fuselage was redesigned for construction in welded steel and hydronalium. Ursinus and later on Hubert were in charge of the aerodynamic design of the wing and Kraemer was head of structural engineering. In order to prevent the wing tip areas from becoming too narrow, we chose a swept wing with a swept-back trailing edge, which would produce a practically elliptical lift distribution. The wing sections were chosen from the NACA profile series. The rudders were installed in a downward and outward position according to the results of the experiments with the *Stork IX*. Heini Dittmar became test pilot for the rebuilt and modified airplane which now had the designation *Delta IVb* (Fig. 43). Since Dittmar was

an extraordinarily gifted pilot he contributed greatly to the final success of the Delta.

Originally we chose an angle of sweepback of 30° (according to the theory by Glauert which exaggerated sweepback). The test flights demonstrated, however, that longitudinal stability in relation to the effectiveness of rudder control was too great, and we therefore rotated both wings forward to obtain a sweepback angle of 23°. Thus the drawings of the *Delta IVc* show the wing sections pointing outward (Fig. 44). Since the test flights showed insufficient directional stability, we widened the rear part of the fuselage and added a narrow rudder to the vertical end of the fuselage. This rudder was linked to the ailerons to correct for negative yaw. The uneven airflow on the midwing section, caused by the effect of the rotating propeller, was compensated for by installing additional winglets above the leading edge on both sides of the fuselage.

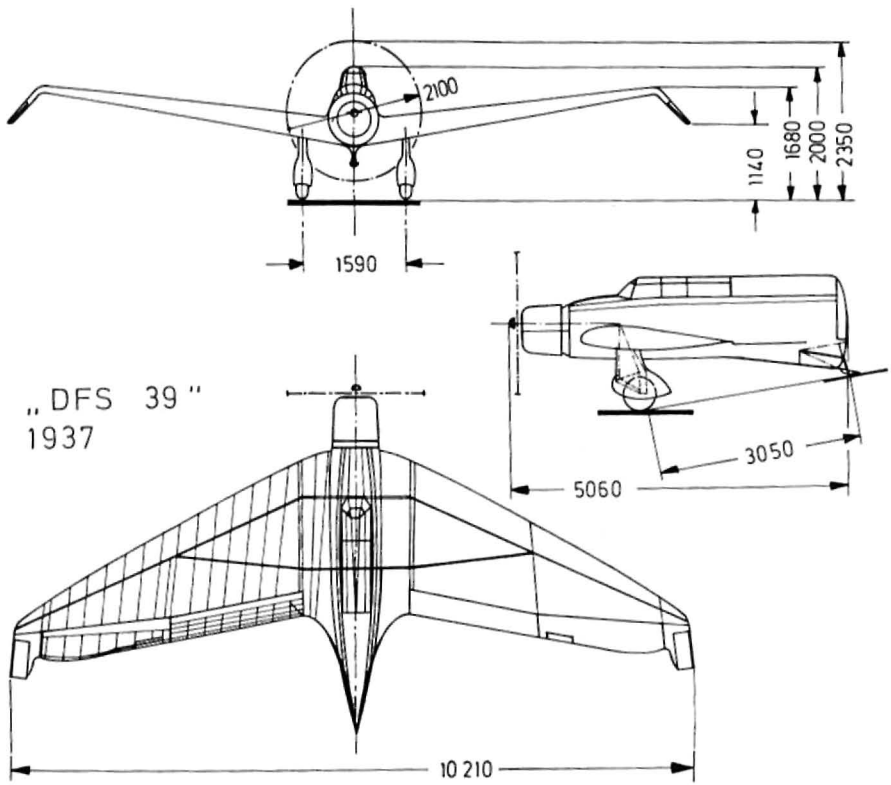
In 1936 the aircraft received the official designation *DFS 39* and after completion of intensive testing at the Federal Flight Testing Center at Rechlin was licensed as a two-place sport aircraft [56]. Dittmar executed most aerobatic maneuvers with this machine and once inadvertently even got into an inverted spin. Since the airflow at the wing-tip sections still tended to stall prematurely, we tested auxiliary wings on the outer wing sections. Such winglets were also used in later designs.

We should not omit mentioning a special project of 1936 which was of unusual design. In England Professor Townsend had shown that by sweeping the wing forward and strongly tapering it toward the tip, stalling at the outer wing section could be effectively postponed. Even at large angles of attack and low speeds, roll stability could thus be maintained, as opposed to the normal swept-back wing where stalling started at the wing tips. To study this problem we designed an experimental glider *Kormoran-DFS 42* (Fig. 45) with forward sweep of the wings, which was built in 1936. We observed the flow by means of filaments and clearly observed the Townsend phenomenon. We took a number of photographs of the wing flow on subsequent flights. However, although the flow on the outer wing remained steady, the flow over the midsection of the wing stalled relatively early causing loss of longitudinal stability and lower maximum lift. We therefore installed an additional rudder over the midwing section which prevented the incipient loss of lift. On the whole, these experiments were interesting but failed to prove any superiority of the wing with forward sweep, since on normal swept-back wings stalling of the outer wing could be prevented by installing wing slots which produced higher maximum lift. From that time on no further experiments with swept-forward wings were carried out by us.

Our work on the *Delta IVc-DFS 39* and the *Kormoran-DFS 42* did not leave time for continuing the development of *Stork IX* types. There still exists a drawing of the *Stork IXc* with enlarged wings, which was not built (Fig. 39). One more high-wing version with swept-back wing was designed as a tailless, powered glider, the *SMS-DFS 38,* which was constructed in 1936 (Fig. 46). This plane was very unsatisfactory in its flying characteristics, since the wing did not possess sufficient torsional strength. We dubbed it "Quo Vadis" (Where are you going?). Due to lack of time we were unable to carry out the intended structural changes. The *Stork X* which was mentioned in a publication by Roth did not reach the construction stage either (Fig. 47).

Since the *DFS 39-Delta IVc* had finally gained good flying characteristics and high efficiency, we obtained additional funds for testing further design variations of swept-back wings.

In 1937 the Research Department of the Air Ministry granted a development contract for a reconnaissance plane as part of our series of high-wing swept-back designs. This version, the *DFS 193* (Fig. 48), was to be built at the Siebel Aircraft Company in Halle-Saale. We built a mock-up of this design, but since the wind tunnel measurements did not show any improvement compared to traditional aircraft types, this project was abandoned in 1938 [48]. At about the same time we received an order for the development of a tailless midwing aircraft with a 100 h.p. Argus engine and a pusher propeller, the *DFS 194* (Fig. 49), to be constructed at the DFS in Darmstadt-Griesheim. It was intended to be an experimental version of a military fighter airplane. This project will be discussed later on.



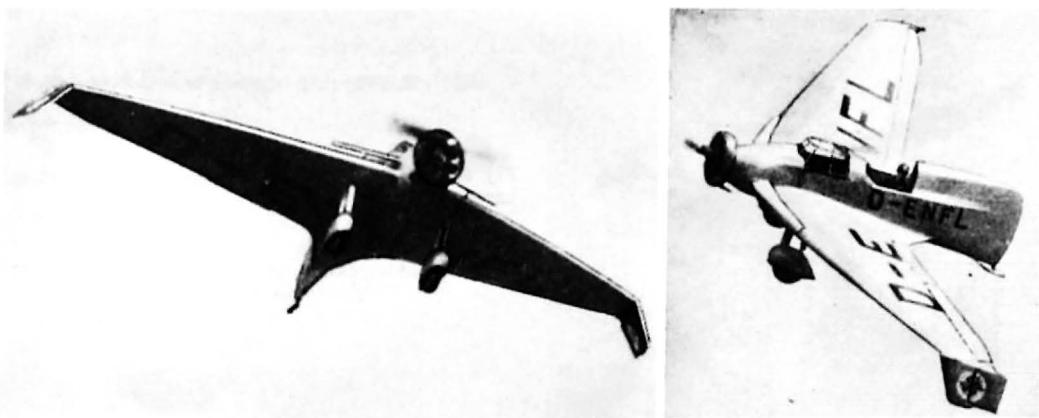
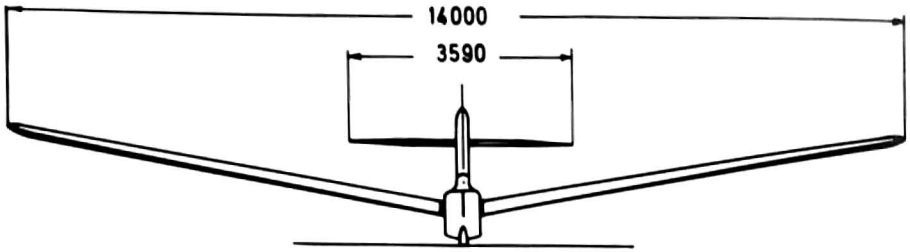
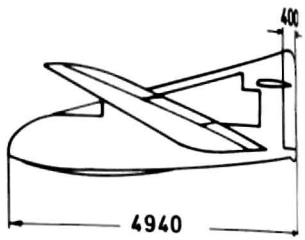


Fig. 44. *Delta IVc—DFS 39* with reduced angle of sweepback (1936).





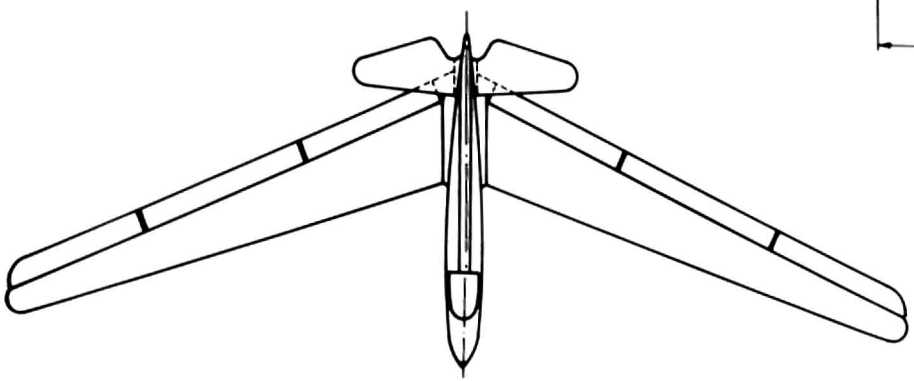


Fig. 45. Experimental glider *Kormoran-DFS 42* (1936). Layout and aircraft in flight.

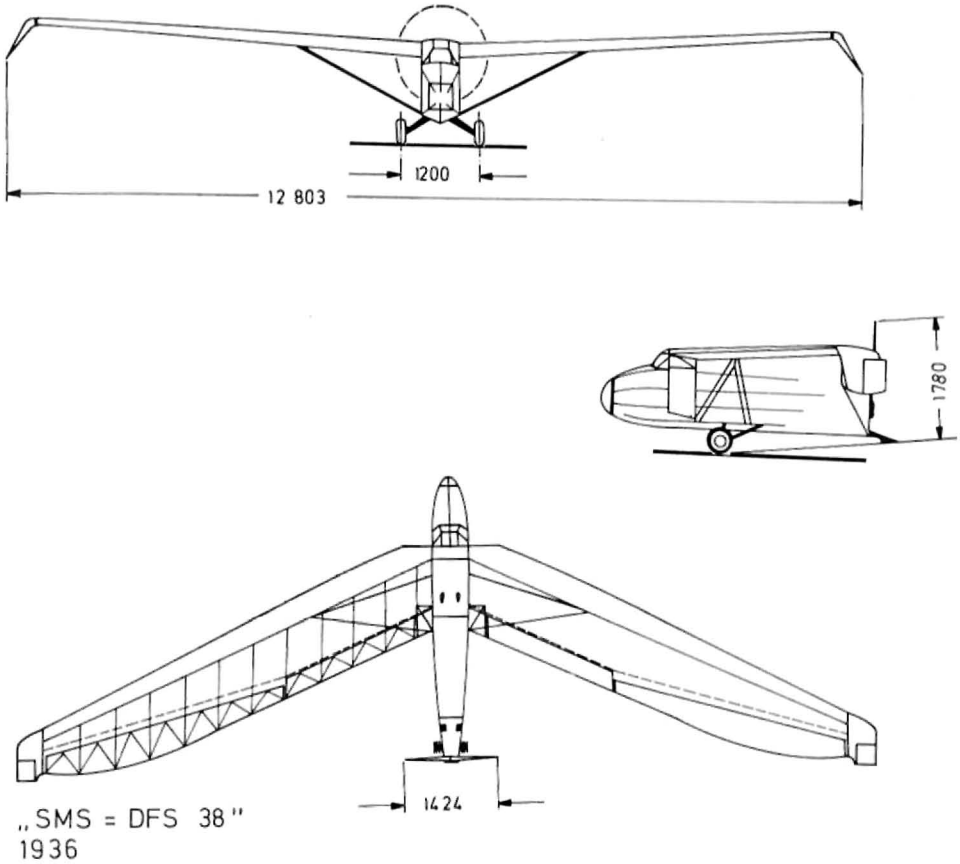


Fig. 46. *SMS* tailless powered glider *DFS 38* (1936).

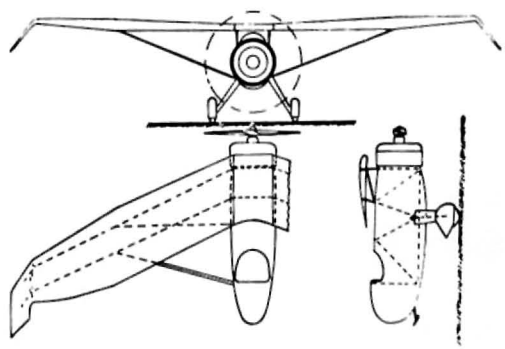
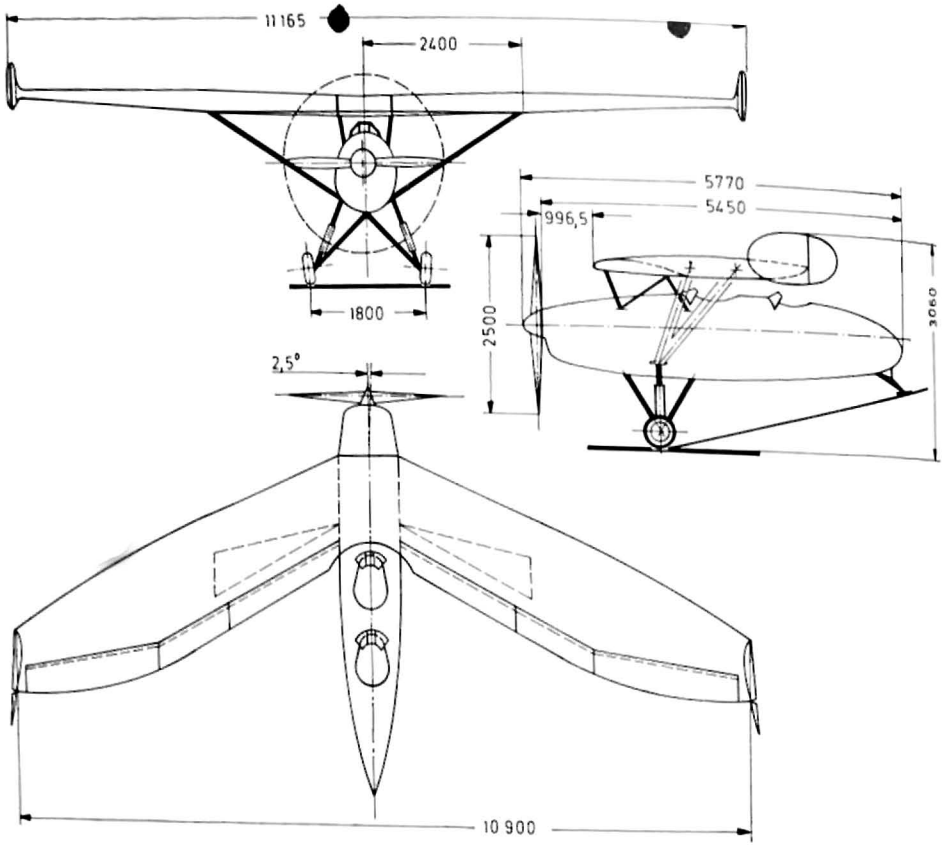


Fig. 47. Project *Stork X* (1937). It was not built.



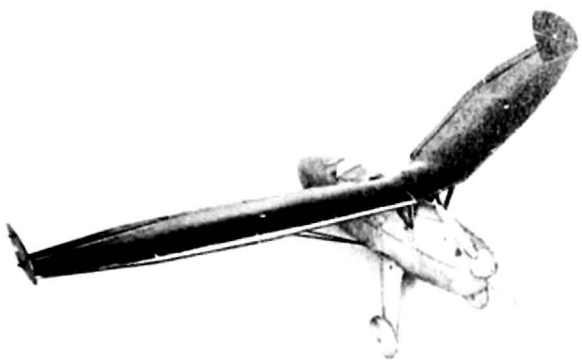
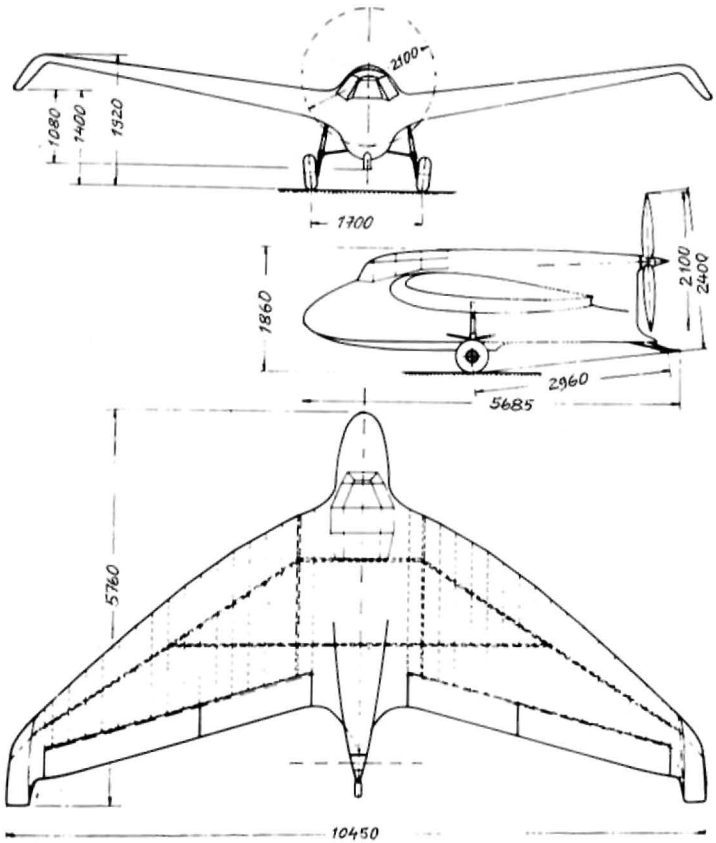


Fig. 48. Reconnaissance aircraft *DFS 193*. Layout and photo of model (1937).



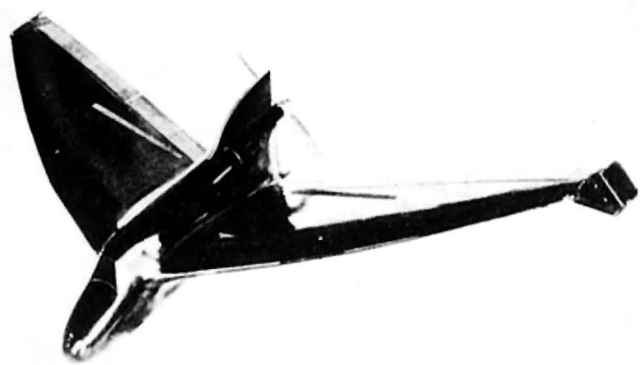
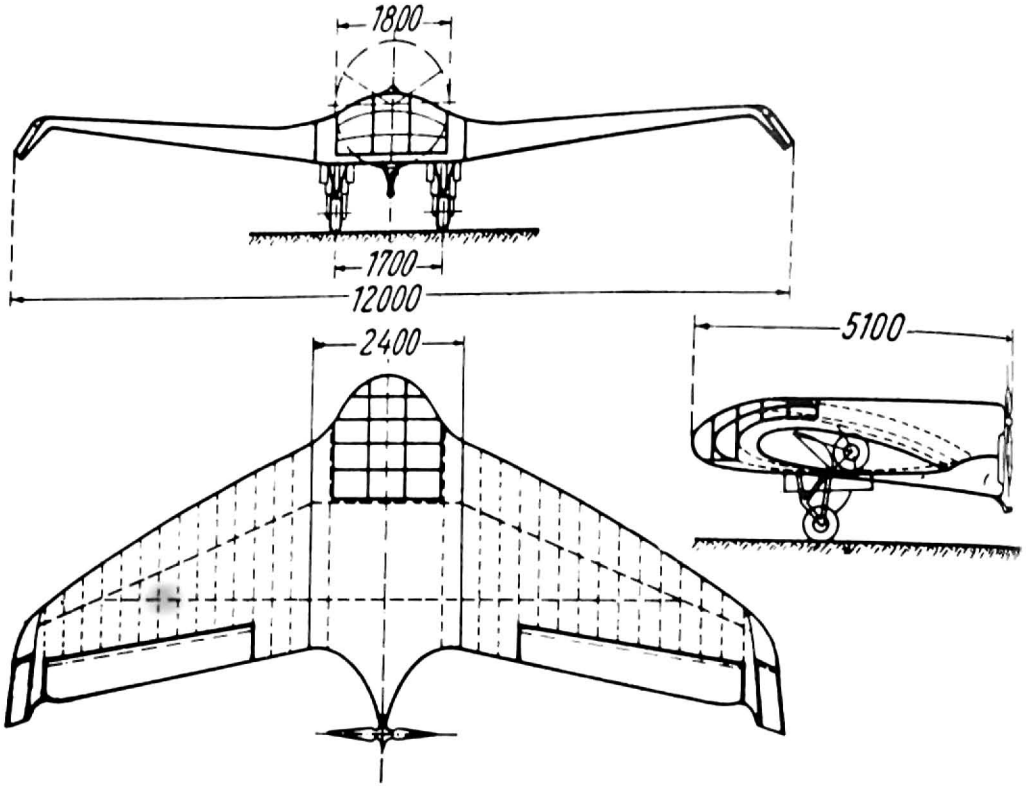
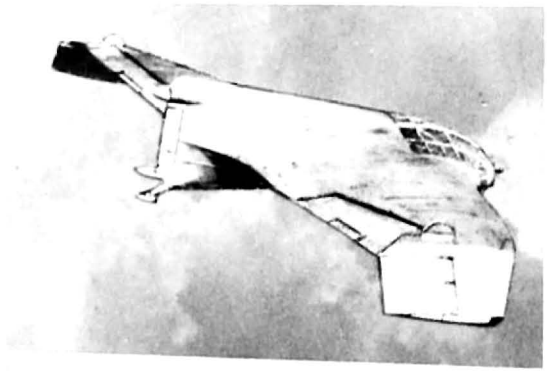
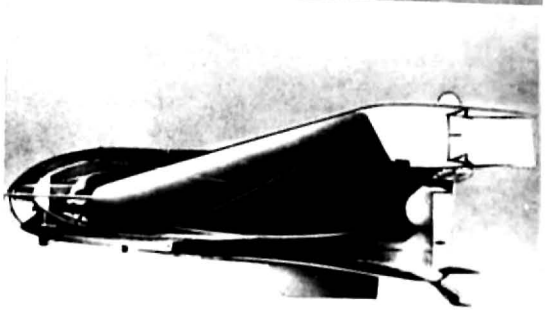


Fig. 49. *DFS 194,* experimental aircraft for a tailless one-man fighter, here without the central rudder. Wind tunnel model 1937.







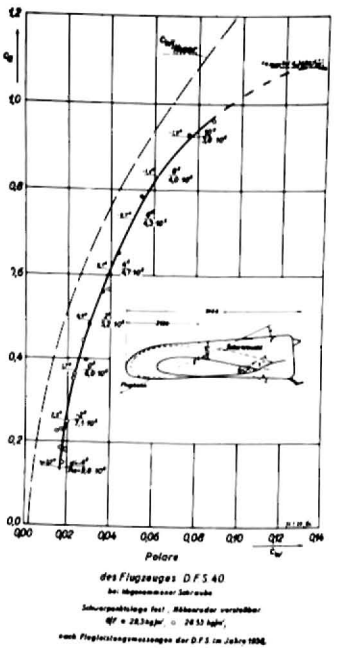
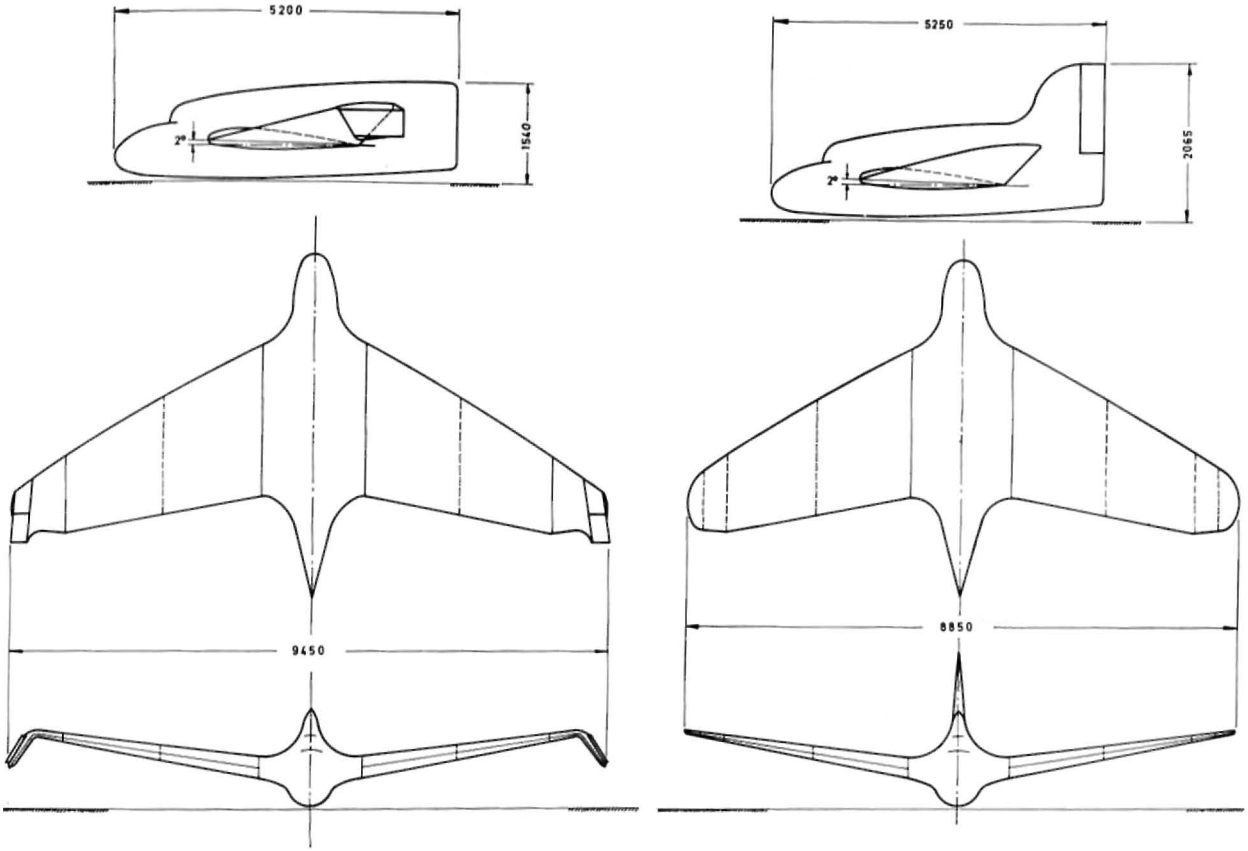


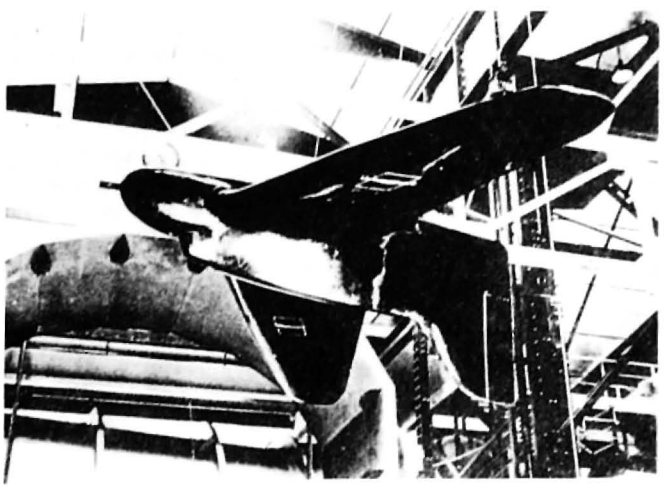
Fig. 50. All-wing experimental aircraft *Delta V-DFS 40* (1937–38). Layout, polar curve, and 2 views in flight.



Project X VERSION *I:* AVA report VI-10-20
J7010 of July 7, 1938

VERSION *II:* AVA report VI-10-20
J7010 of July 7, 1938

Fig. 51. The first 2 wind tunnel models for *DFS 39d-Project X* without and with central rudder (July 7, 1937). Later the dihedral was taken out. Layout and wind tunnel model.



In 1937 I also designed a pure all-wing aircraft, the *DFS 40-Delta V* (Fig. 50), in order to be able to compare as many versions of tailless designs as possible. Before installing the engine we carried out a thorough flight-testing program and plotted the polar values in flight. The *DFS 40* was laid out for propulsion by a pusher propeller with a 100 h.p. Argus engine and was test-flown by Heini Dittmar at the DFS in Darmstadt in 1939. It

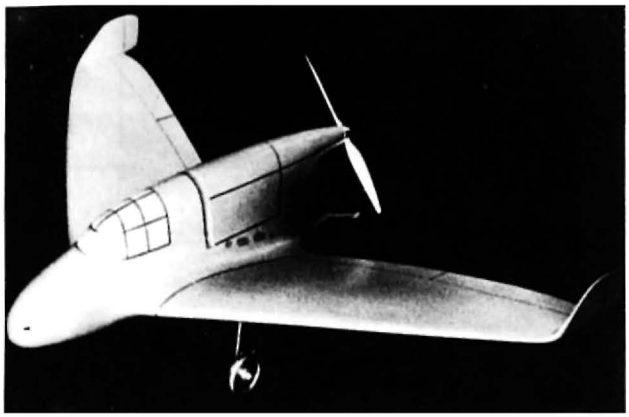


Fig. 52. Demonstration model of a fighter presented to Ritter von Greim (1938).

showed very remarkable performance [56]. After my departure from the DFS at the end of 1939, Heinrich Voepel was in charge of the test program. Due to an error in weight distribution, the center of gravity was too far aft and caused the airplane to enter a flat spin. The airplane was completely destroyed in the ensuing crash. Fortunately the pilot was able to parachute to safety.

In 1937, following a visit by Dr. Lorenz to the DFS, the Research Department of the Air Ministry, headed by Dr. Baeumker, ordered a tailless aircraft which would be especially adapted to testing rocket propulsion. Since at that time the *Delta IVc* was our most advanced design, the new *Project X-Delta IVd* closely resembled that type. This order was to be treated as highly confidential. It was to be built partly at the facilities of the DFS in Darmstadt but construction was to be carried out mainly at the Heinkel Aircraft Company in Warnemünde. The results of the wind tunnel measurements and tests with free-flight models under the supervision of J. Hubert (aerodynamics) and R. Rentel (structural engineering) led to a number of modifications of the original design (Fig. 51). Since the wing-tip rudders proved inappropriate for high velocities because they touched off wing flutter, a central rudder was installed (Fig. 51). Later on the dihedral of the wing was completely taken out. The aerodynamic characteristics of the fuselage were greatly refined and incorporated in the lift distribution of the wing. All these measures were intended to produce stable flying characteristics over the whole speed spectrum. On all subsequent designs the central rudder—as opposed to wing-tip rudders—was used.

Figure 52 shows the model of a tailless single-place fighter which we gave to General Ritter von Greim, who at that time was one of the few supporters of the DFS.

5 Work at Department "L" of the Messerschmitt A.G.

5.1 DEVELOPMENT OF *ME 163 A* AND *B*

SINCE collaboration with Heinkel appeared problematic and the continuation of the development of this experimental high speed craft was questionable at the DFS, I decided to transfer to the Messerschmitt A.G. in Augsburg. On January 2, 1939, I moved to Augsburg with most of my closest coworkers.

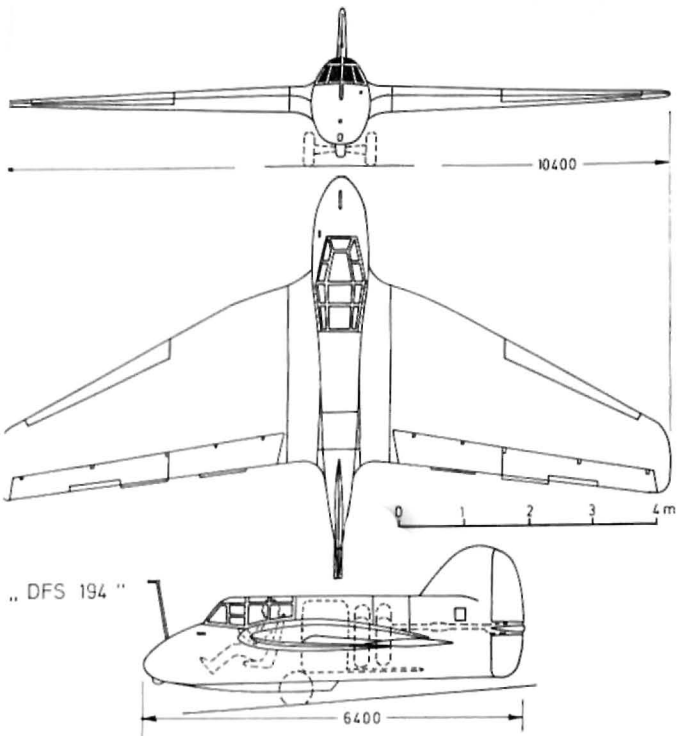
The members of the team were the following: Hubert, Beushausen, Guthier, Ringleb (aerodynamics); Görner, Sielaff (stress analysis); Rentel, von der Forst, Hartmann, Brecht (structural engineering); Hamburger, Elias, Kropp (shop); Dittmar (pilot); and Hartz (administration). At the Messerschmitt Company our group was designated Department "L" and was assigned the task to develop "Project X," which was now given the designation *Me 163*. At the same time the supervision at the Air Ministry passed from the Research Department to the Development Department, which was headed by Antz.

The structure of the *Me 163* was revised and the fuselage was changed to light metal construction, which was used throughout at the Messerschmitt Company. When in September 1939 World War II broke out, the *Me 163* program was stopped and we occupied ourselves with several short-term projects which will be discussed later.

Let us return to the *DFS 194* which was built in 1937 at the DFS as an experimental prototype of a tailless fighter, under contract from the Research Department of the RLM. The *DFS 194* was a shoulder wing design with swept-back wings with a positive dihedral and downward deflected wing-tip control surfaces. It was laid out for a pusher propeller and a 100 h.p. Argus engine (Fig. 49). A test model of this design was measured in the Göttingen wind tunnel. The test results showed 83 percent efficiency for the propeller, which was calculated on the basis of Glauert's method.

When we transferred to Messerschmitt, work on the construction of the *DFS 194* had not been completed. With the outbreak of WW II the priority rating of *Project X-Me 163* was reduced. We modified the unfinished structure of the *DFS 194* according to the results of the wind tunnel measurements and our experience with free-flight models of "Project X," which had been renamed *Me 163*. In this way we were able to carry out at least preliminary tests with the Walter rocket engine. The modifications included eliminating the dihedral of the wing and replacing the wing-tip controls by a central rudder which was attached at the end of the slightly lengthened fuselage. In addition we decided on a detachable undercarriage for takeoff, while the landing was to be performed on a skid (Fig. 53). Let me stress, however, that the *DFS 194* should in no way be regarded as a predecessor of the *Me 163*. The *Me 163-Delta IVd* was derived directly from the *Delta IVc-DFS 39*.

The modified *DFS 194* was sent to Peenemünde-West for installation of the Walter rocket engine [56]. There the aircraft was checked out again and the power plant and tank were installed in the shops of the testing ground. Stationary trial runs of the rocket engine followed. The first



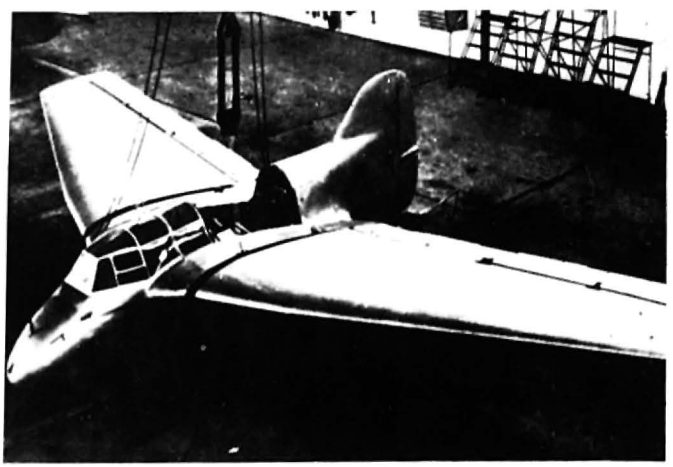


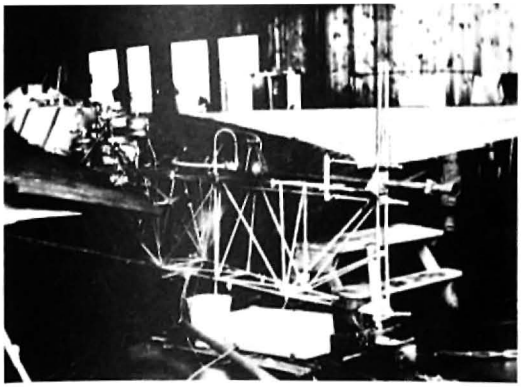
Fig. 53. Airframe of the *DFS 194*, after modification for rocket-powered flight (1940).

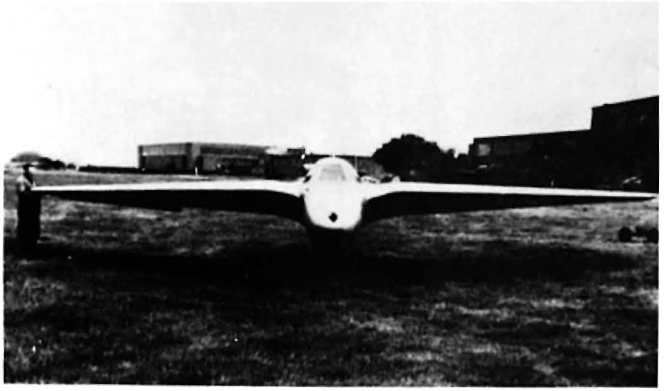
rocket-propelled flight took place in August 1940 on the airfield of Peenemünde-West with Heini Dittmar at the controls (Fig. 54). To measure flight performance an Askania 4-variable recorder had been installed which gave valuable data on the flight characteristics of the aircraft with rocket propulsion. Velocities up to 550 km/h were attained. Further increase of maximum speed could not be attempted due to slack in the control cables. These test flights, which on the whole proved very successful, led to an increase in the priority rating of the *Me 163*. Consequently we were able to complete one of the *Me 163* airframes on which work had been started at the Messerschmitt Company. The aircraft was test-flown without an engine in Augsburg after being towed to the necessary altitude by a *Me 110* (Fig. 55a).

The wind tunnel measurements, which had been carried out in Göttingen while the project was still at the DFS, had shown the remarkable aerodynamic quality of the test model (Fig. 51). The test flights fully confirmed these results. The aerodynamic design of the fuselage and fuselage-wing fairing had contributed markedly to the improvement. Since the excellent glide angle was not desirable when landing, we added braking flaps on the underside of the wing, which also contributed somewhat to maximum lift (Fig. 56).

In the summer of 1941 the first airframe with the designation KE+SW (Fig. 55 b–e) was transported to Peenemünde where a Walter rocket of 750 kg thrust was installed. The test flights of the *Me 163*, later designated *Me 163 A*, were piloted by Heini Dittmar and were completed on October 2, 1941, with a flight that reached a velocity of 1003 km/h corresponding to 0.85 Mach. This represented an unofficial world record which could not be made public because of the secrecy requirements [56]. This successful performance motivated the RLM to draw up a program for an interceptor fighter with rocket propulsion.

We at Department "L" had been thinking about such an application for quite some time and had worked on a number of projects of this kind. These preliminary designs included projects with reciprocating engines and turbojets, since we did not want to be tied exclusively to a source of pro-





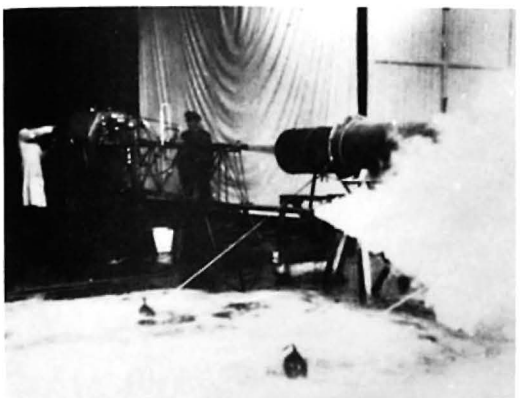
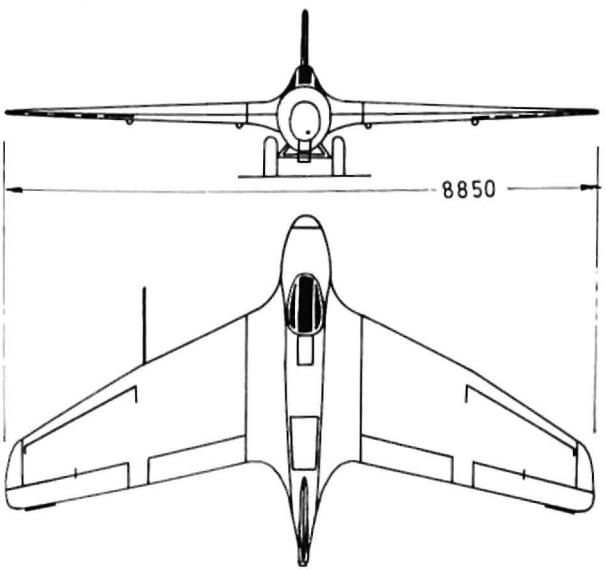
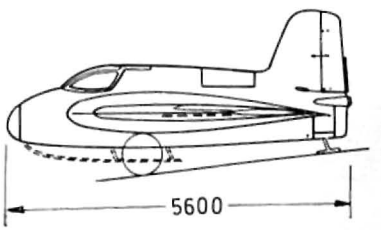


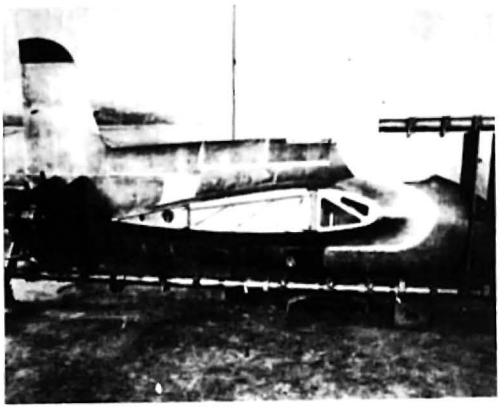
Fig. 54. Installation of the rocket engine in Peenemünde and first rocket-propelled flight of the *DFS 194* in 1940.

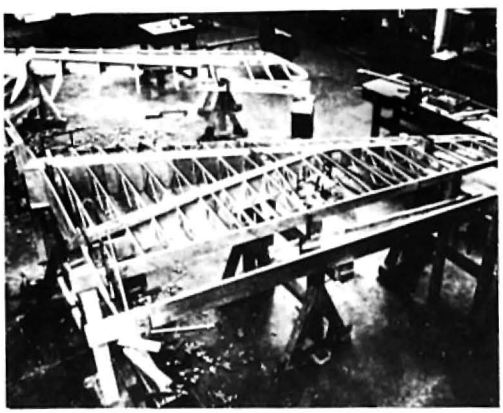




„ Me 163A - 1 "

Fig. 55a. Layout of *Me 163 A-1.*





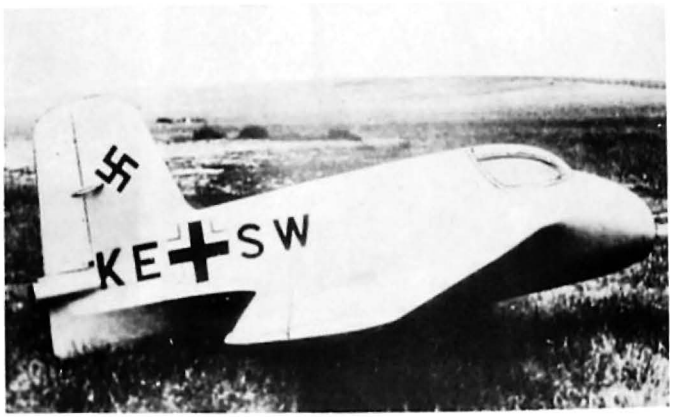


Fig. 55b–e. *Me 163 A:* (*Left*) construction of fuselage and wings; (*Right*) view of the first finished aircraft.

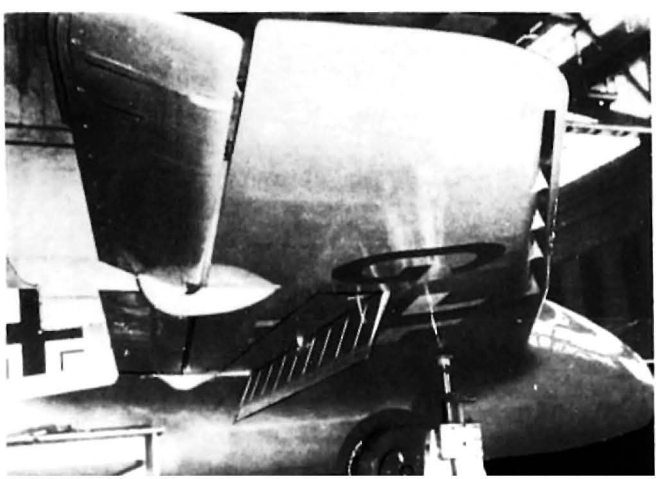


Fig. 56. *Me 163 A.* Wing with leading edge slot, landing flap, and aerodynamically balanced control flaps.

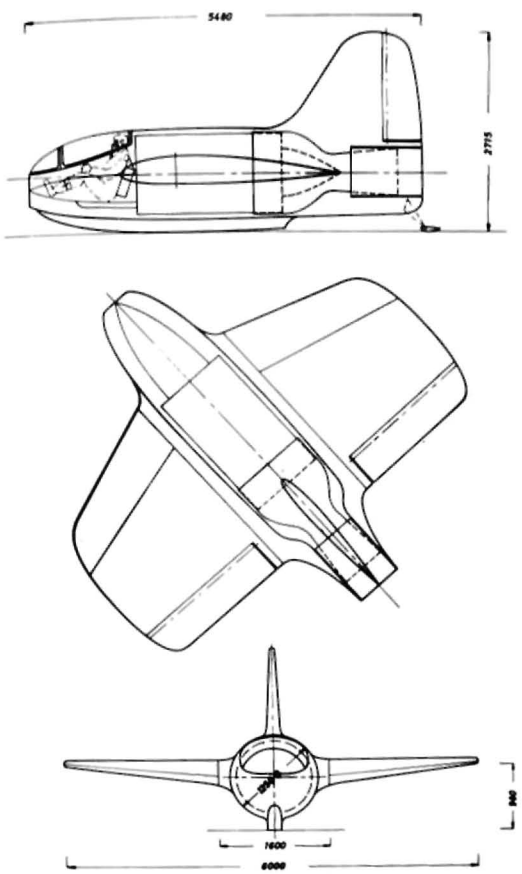


Fig. 57a. Project *P 01-116* for a one-place aircraft with turbojet engine (April 1939).

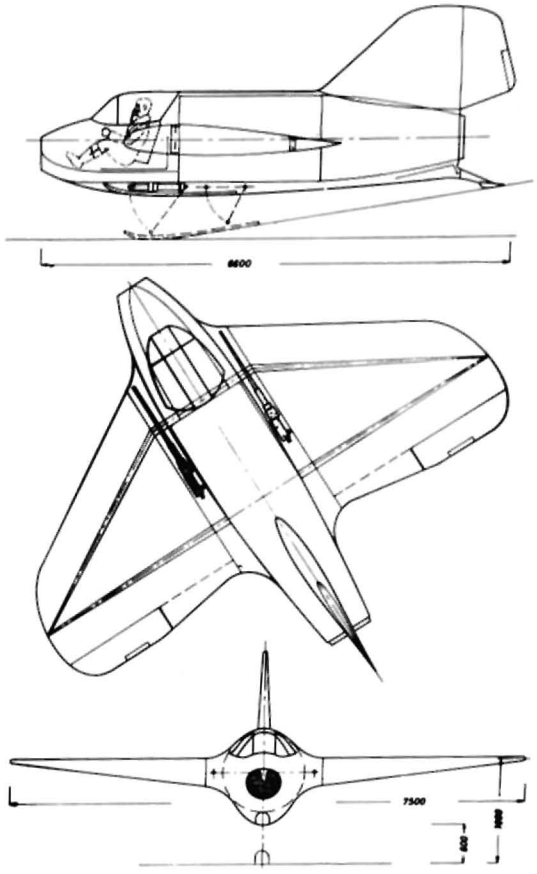


Fig. 57b. *P 01-111* for a turbojet fighter (November 1939).

pulsion which was as yet insufficiently tested. The first project for an interceptor fighter was the *P 01-116* (April 12–13, 1939). This design was based on the first available data for a turbojet (Fig. 57a). An improved midwing version, conceived on October 20, 1939, was designated *P 01-111* (Fig. 57b). Project *P 01-112* of January 31, 1940, was a high-wing arrangement. In this project air was tapped from both turbines and blown over the top of the wing (Fig. 57c). The next design, *P 01-113* of July 17, 1940, was a high-wing version with both rocket and turbojet propulsion (Fig. 57d). The design *P 01-114* of July 19, 1940, was identical except that it was equipped with a rocket engine (Fig. 57e).

After a lapse of almost a year which was filled with intensive work on the *DFS 194* and the *Me 163*, we renewed our project design work. In the spring of 1941 we conceived a version of the *Me 163* with greatly improved aerodynamic properties, the *P 03-Me 263* (see Fig. 58 and Appendix). This project was designed as a test aircraft for higher velocities. The angle of sweepback was 32.1° (compared to 23.4° of the *Me 163*). The wind tunnel model of this design was tested at the AVA in Göttingen and the measurements showed an

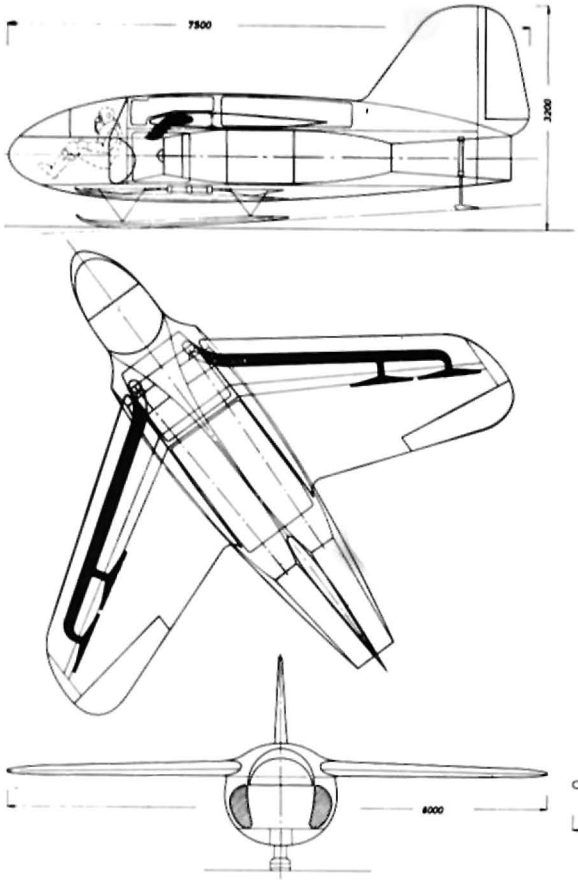


Fig. 57c. Project *P 01-112* for a turbojet fighter with forced air flow over the top of the wing (February 1940).

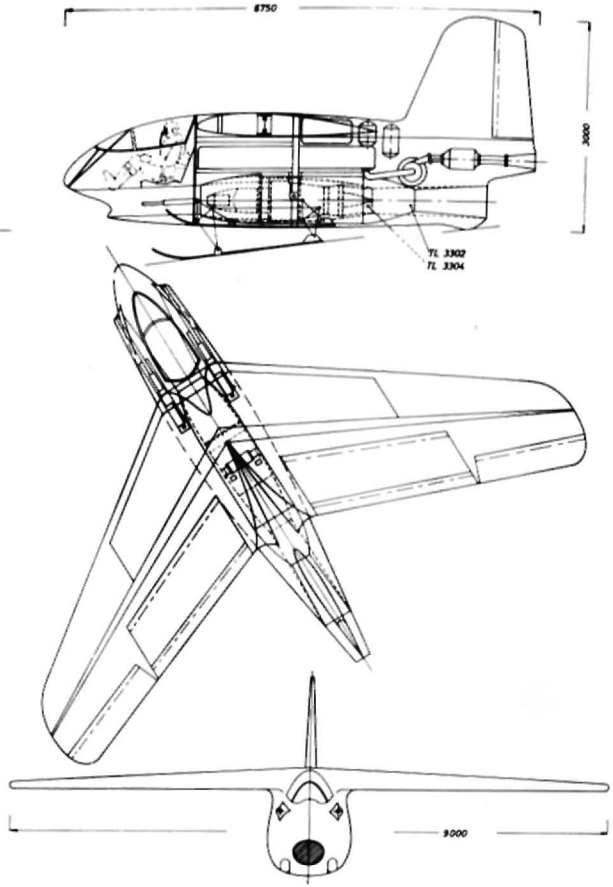


Fig. 57d. Project *P 01-113* for a fighter of mixed propulsion (turbojet and rocket) (July 1940).

extremely low friction coefficient (see Appendix). However, work on this project was stopped when the *Me 163* passed the 1000 km mark.

In the course of the work on the *P 01* fighter series the AVA measured a model with several interchangeable parts, testing varying fuselage designs and wing outlines in different wing positions (Fig. 57f). The effect of stationary horizontal stabilizing surfaces was also examined. A further project of that period was the *P 01-115* of July 2, 1941, a midwing version with turbojet and rocket propulsion where the air intake was placed above and behind the canopy (Fig. 57g). Project *P 01-116* of June 12, 1941, was a midwing interceptor fighter with turbojet propulsion (Fig. 57h). A project dated July 16, 1941, which also carried the designation *P 01-116,* represents a rocket-propelled interceptor (Fig. 57i). These last two projects and later *P 01* versions had a wingspan of 9.0 m. Project *P 01-117* of July 22, 1941, shows an interceptor with prone position of the pilot (Fig. 57j). Project *P 01-118* of August 3, 1941, featured a swivel pilot seat to enable the pilot to maintain a horizontal field of vision in a climb (Fig. 57k). It envisioned

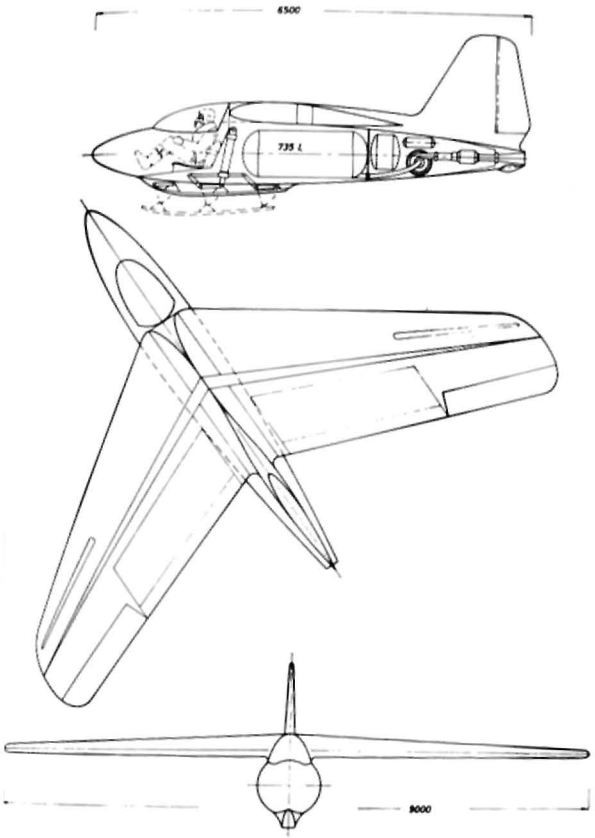


Fig. 57e. Project *P 01-114* of a rocket fighter (July 1940).

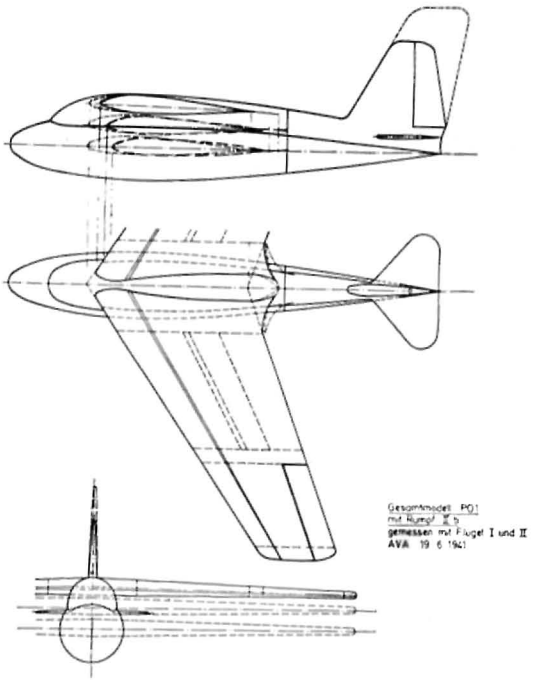


Fig. 57f. Wind tunnel model *P 01* which was measured in Göttingen in different interchangeable configurations (June 1941).

the installation of two rocket power plants, one for climbing and one for cruising. Project *P 01-119,* dated August 4, 1941, had a pressurized cabin (Fig. 57l). On August 25, 1941, project *Li P 05* represented an interceptor (Fig. 59) with four rockets, three for climbing with 1500 kg thrust each and an adjustable cruising rocket with 750 kg thrust. This was a true-to-scale enlargement of the *Me 163 V4* to ensure the design of an aircraft of known characteristics, good weaponry (four machine guns), and great range. However, since it was feared that in this aircraft of 12.8 m wingspan the control forces would be too high, it was decided to return to the smaller size. On September 14, 1941, we produced a smaller design, the *Li 163 S* (*S* for series production) with a wingspan of 9.2 m that was to be armed with four machine cannons (Fig. 60). The final choice, however, was a design with the designation *Me 163 B* (Fig. 61a). It was to be powered by a "hot" rocket of 1500 kg thrust and was to be armed with two automatic cannons, one on each side of the fuselage in the wing roots. The wing of 9.3 m span had a sweepback angle of 23.4°. Construction was started on De-

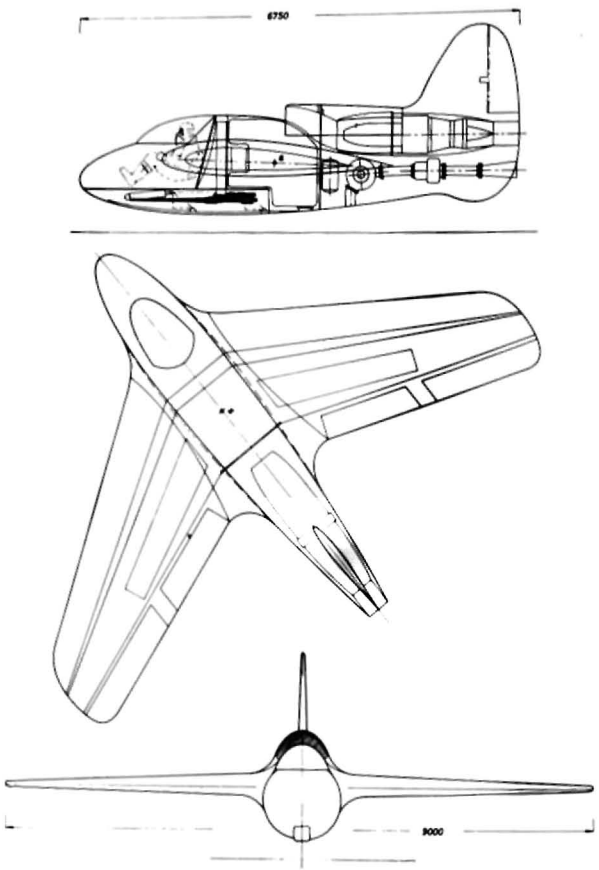


Fig. 57g. *P 01-115* with mixed propulsion (July 1941).

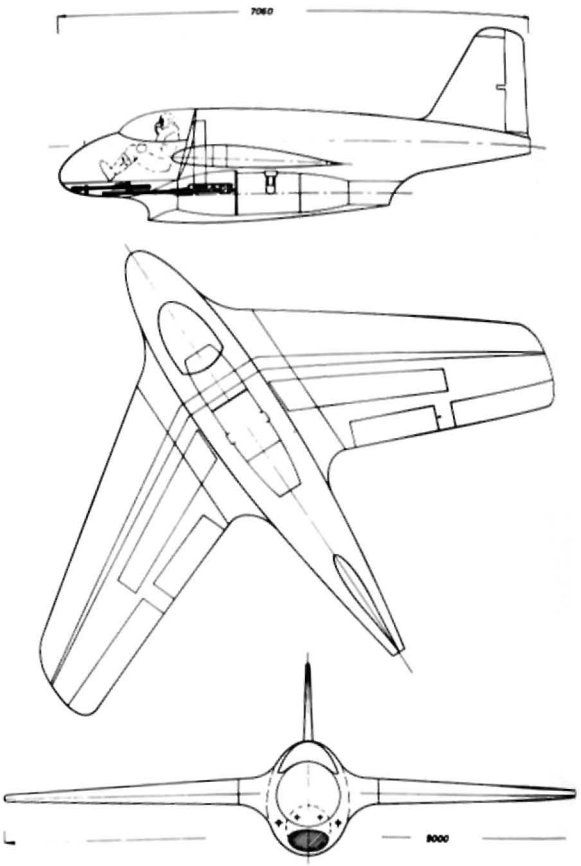


Fig. 57h. *P 01-116* with turbojet propulsion (June 1941).

cember 1, 1941. Seventy aircraft had been ordered and were given a high priority rating. [General Ernst Udet, a famous fighter pilot of World War I, was head of the Technical Department of the Air Ministry. He had strongly supported the *Me 163* project when, on the occasion of a visit to the Messerschmitt Company, he witnessed a test flight of the *Me 163* that was carried out without power. The *Me 163* had been towed aloft by a *Me 110*.] However, after Udet's death on November 17, 1941, the rating was lowered by General Milch, who took Udet's place in the Air Ministry. This caused great delays, especially in the rocket production at the Walter Company in Kiel. In May 1942 the first completed airframe of the *Me 163 B* could therefore only be tested in towed flight. The first "hot" start took place in July 1943. The first fully armed *Me 163 B* (*V 14*) powered by the "hot" production rocket *R II-211* (RLM designation 109-509) was delivered to the test squadron as late as January 1944 [75].

The *Me 163 B* took 2½ min to reach an altitude of 9150 m and 3 min to climb to 12,000 m. Powered flight was limited to 8 to 15 min. Range was about

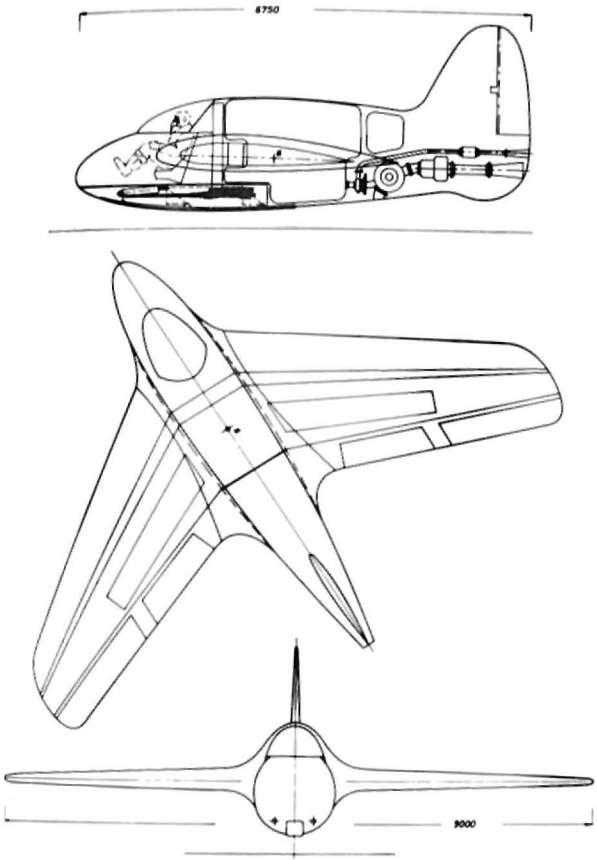


Fig. 57i. *P 01-116* with rocket propulsion (July 1941).

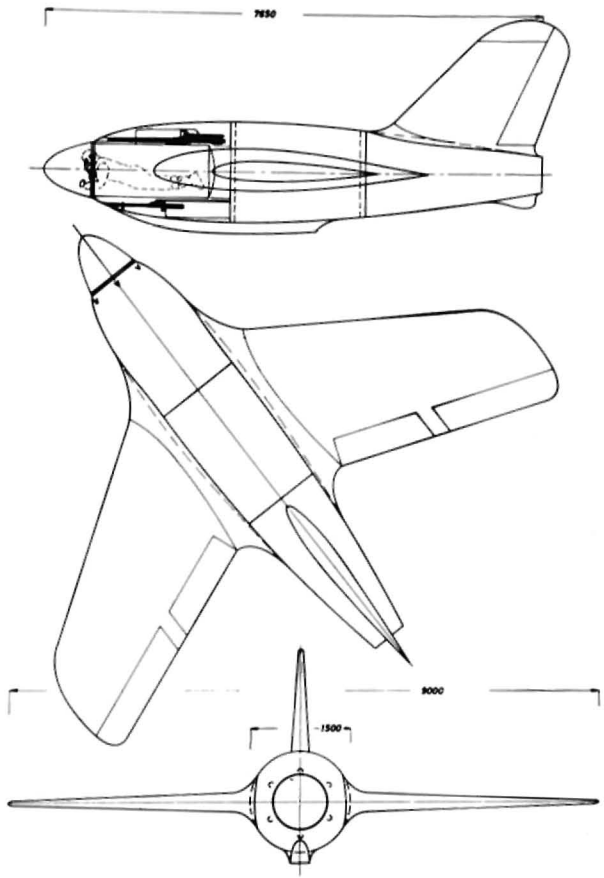


Fig. 57j. *P 01-117* with pilot in prone position (July 1941).

100 km. Testing of the *Me 163 B* in action showed that due to the high approach velocity the pilot had only 3 sec for aiming, which accounted for poor accuracy in firing the two cannons that had a relatively slow firing sequence.

Because of accidents with the unreliable rocket engine, lack of trained pilots and fuel, and frequent relocation of the flight bases away from the threatened Eastern war front, only 25 percent of the 279 *Me 163 B* aircraft built by the end of the war ever reached military action.

The Wolf Hirth Company built 10 *Me 163 A* aircraft without rockets which were to be used for pilot training. The *Stummelhabicht* (i.e., the glider *Habicht* of the DFS with reduced wingspan), served as a first step for this project.

In the course of the development of the *Me 163 B* two further versions were tested in the form of models at the AVA Göttingen. The first of these was the *Me 163 C* with a warped wing. As expected, decreasing the angle from 6° to 0° resulted in an increase of the maximum admissible Mach number at a loss of stability. The second project was the *Me 163 D* (Fig. 62). In this design

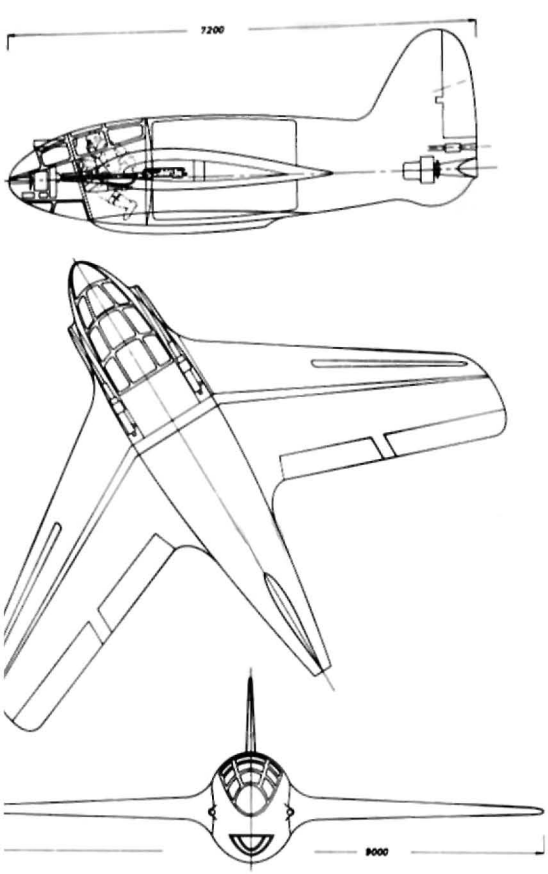


Fig. 57k. *P 01-118* with swivel pilot seat.

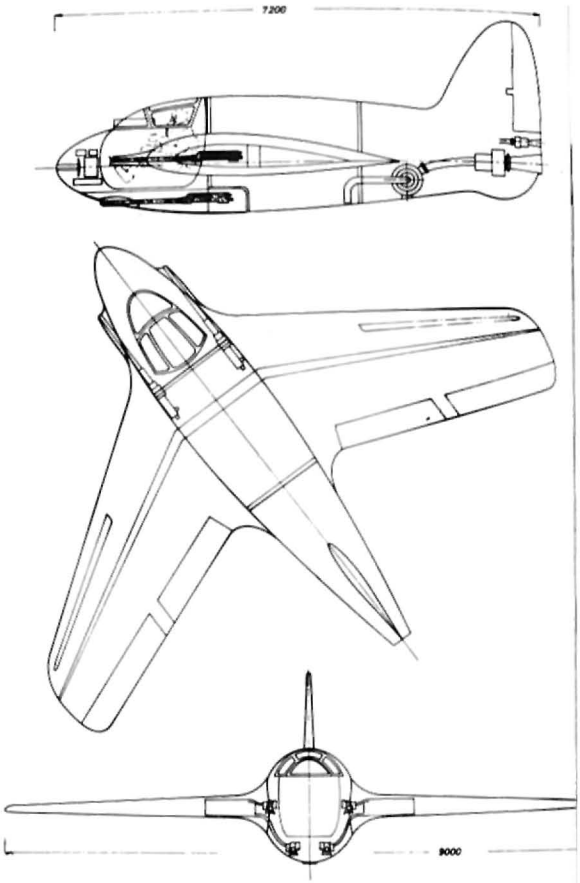
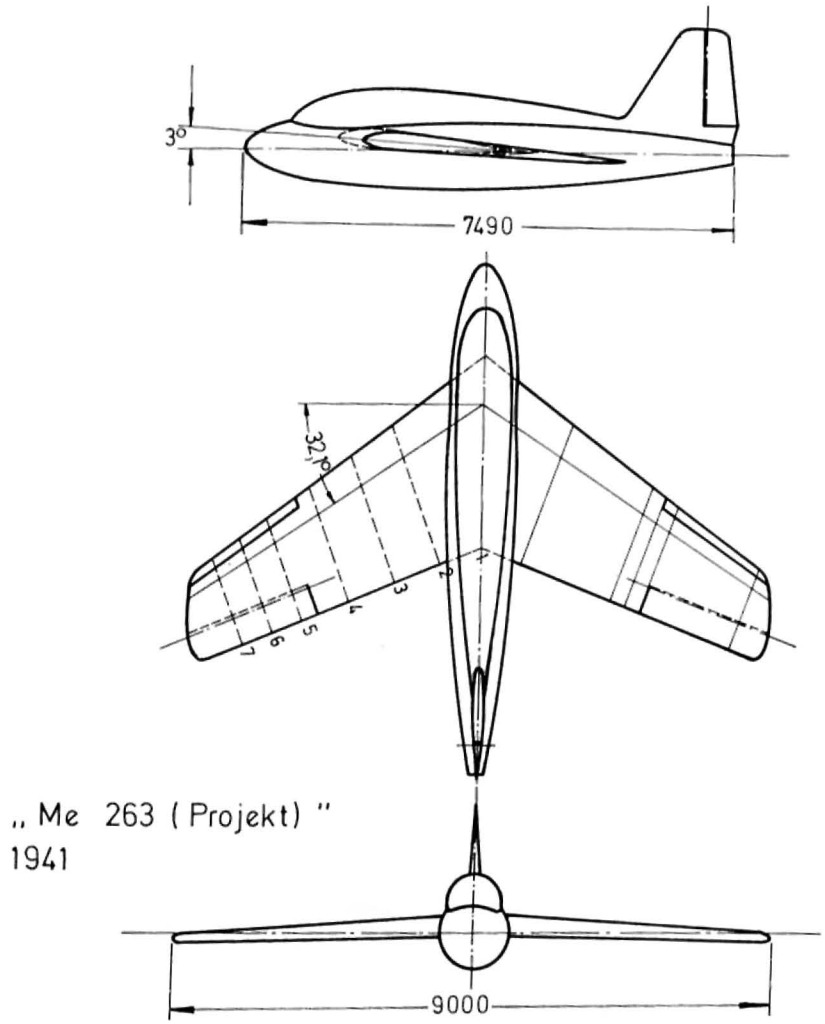


Fig. 57l. *P 01-119*, last version of this series (August 1941).

the fuselage was lengthened by 1 m to improve fuel capacity. The wind tunnel measurement of this model showed only a small increase in the drag coefficient. The increase of the wing loading, which already greatly exceeded the originally calculated values, would have necessitated an increase of the wing area. These two projects could not be pursued further because of other urgent work and are not related to the later types of this designation.

Takeoff of the fully loaded *Me 163 B* presented difficulties, especially on airfields at the war front where the runways were inadequate. There was the danger of fire and explosion of the two fuel components and there were problems with separation of the undercarriage. Therefore in the summer of 1943 the Messerschmitt flight-test group in Peenemünde started experiments with a launching platform on a normal railroad track of 1000 m length. Two solid fuel rockets, of 9000 kg (19,800 lb) thrust each, accelerated the launching platform to a speed of over 300 km/h. The plat-



58. Proposal *P 03-Me 263*, high speed aircraft with rocket propulsion, about June 1941 (see Appendix 8).

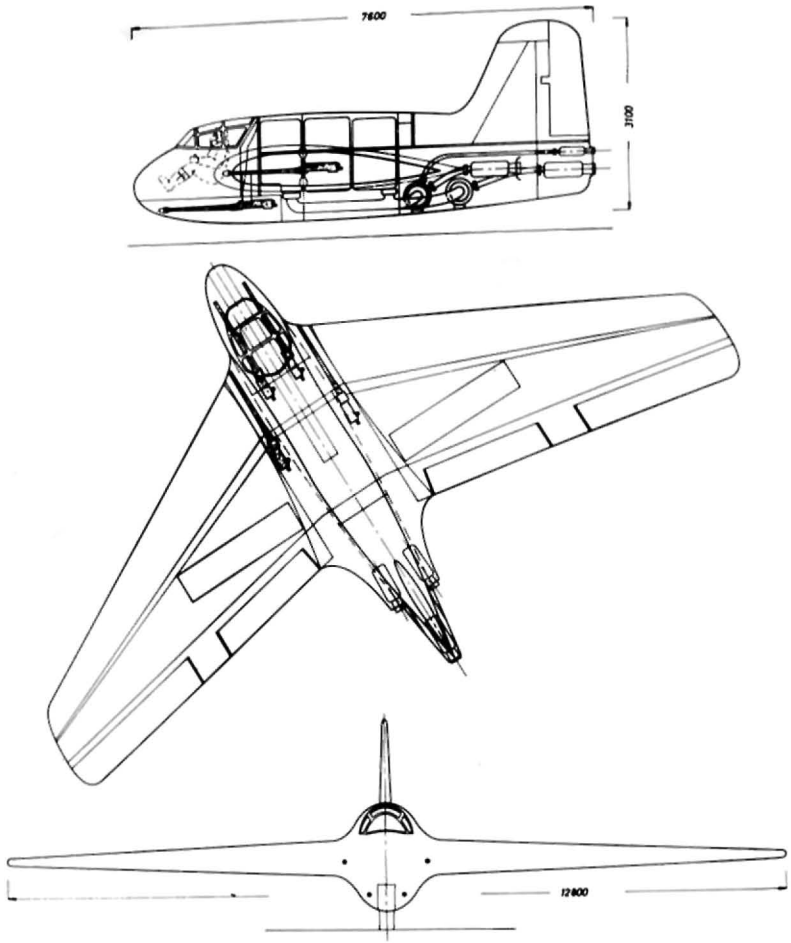


Fig. 59. Project *P 05* of a rocket fighter with two engines (August 1941).

form was equipped with a pneumatic braking system which pressed two braking pads with an area of 1.2 m^2 to an I-profile installed between the tracks. The aircraft rested on a catapult and was released automatically. The wooden mock-up aircraft that were used for the tests were produced by the Graf Hagenburg Company in Sonthofen. They were brought to the regular starting weight of 4.2 t and the correct center of pressure by means of ballast and the correct starting position was obtained by trimming the elevators. The first three takeoff attempts were failures because of a mistake in the stress calculations of the mock-up aircraft. In several consecutive tests the wooden models exploded suddenly at a speed of about 190 km/h within a margin of less than ±3 km/h. In spite of the failures this consistency spoke for the excellent craftsmanship of the producer. The mistake was soon found but the tests had to be suddenly stopped because of the relocation of the Flight Test Group in August 1943 (Fig. 61d).

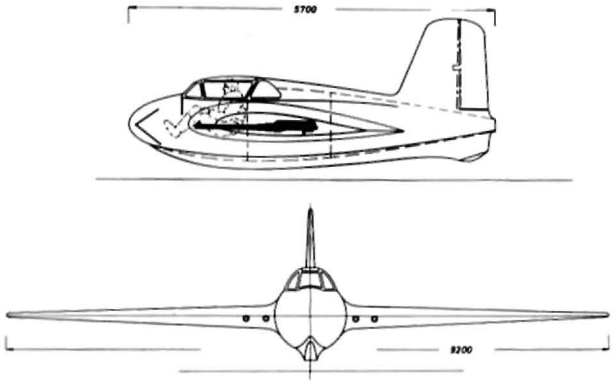


Fig. 60. Project *Li 163 S*, last preparatory step in the development of the *Me 163 B* (September 1941).

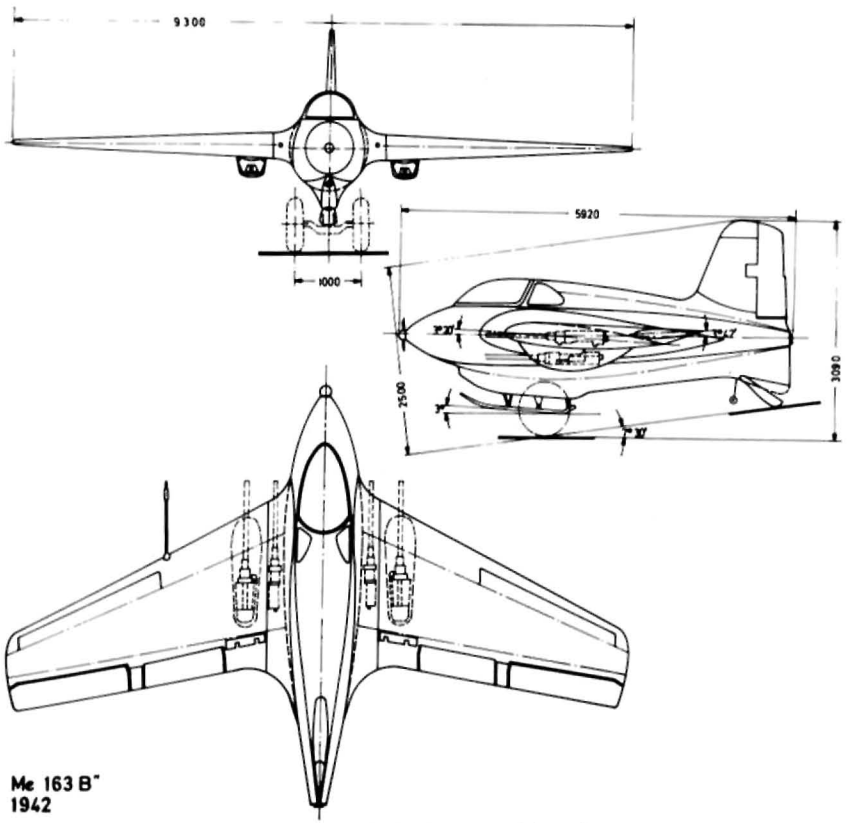
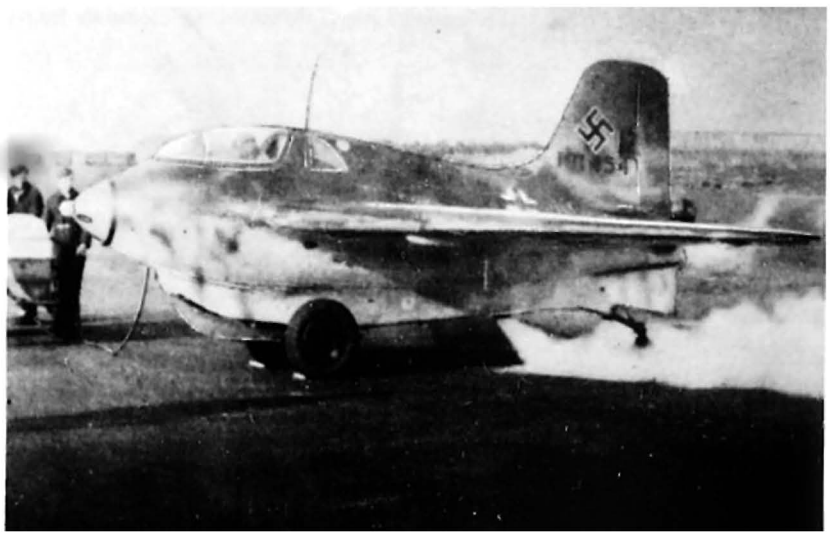


Fig. 61a. Rocket fighter *163 B*, layout.

b

c



d

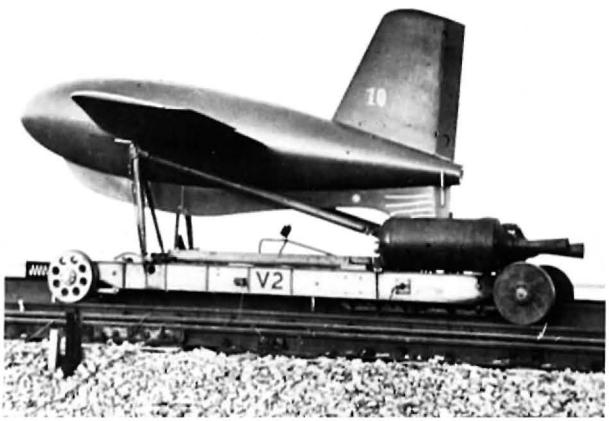
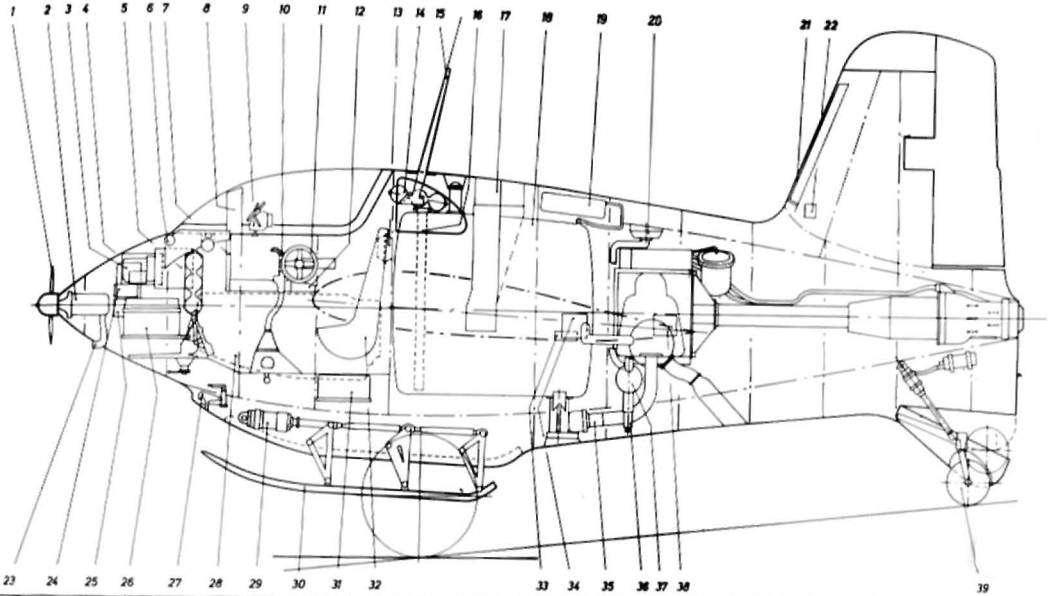


Fig. 61b–d. Two views of *Me 163 B*, 1942. Wood-constructed mock-up of *Me 163 B* on launching platform (Peenemünde, summer 1943).



1. Generator Drive Propeller
2. Generator
3. Transformer for Transmitter
4. Rudder Pedals
5. Radio Transmitter 16 ZE
6. Vacuum Bottle for Variometer
7. Instrument Panel
8. Armored Glass, 90 mm
9. Reflector Gunsight 16 B
10. Control Column
11. Trim Control
12. Radio Panel
13. Warning Horn for Critical Mach
14. Oxygen Bottles
15. Antenna
16. Filler Pipe for T-Stoff
17. Ammunition Feed Belt
18. T-Stoff Tank
19. T-Stoff Starter Tank
20. Filler Cap for C-Stoff
21. Sensing Antenna
22. Antenna Matching Unit
23. Intake for Generator Ventilation
24. Filter for Receiver
25. Voltage Regulator
26. Battery Box
27. Tow-bar Attachment Point
28. T-Stoff Cockpit Tank
29. Hydraulic Cylinder for Skid Operation
30. Skid
31. IFF Receiver 25 a
32. Pilot's Seat
33. Gun Charger
34. Distribution Fuse Box
35. Emergency Drainpipe
36. Drainpipe for C-Stoff
37. Acceleration Tank
38. Fuel Control and Distribution Box
39. Tail Wheel

Armament
2 Machine Guns in Wing Root (up to V 45)
2 Machine Cannons in Wing Root (V 46–V 70)

Fig. 61e. Longitudinal section of *Me 163 B* with rocket engine HWK 109-509 A (July 1943).

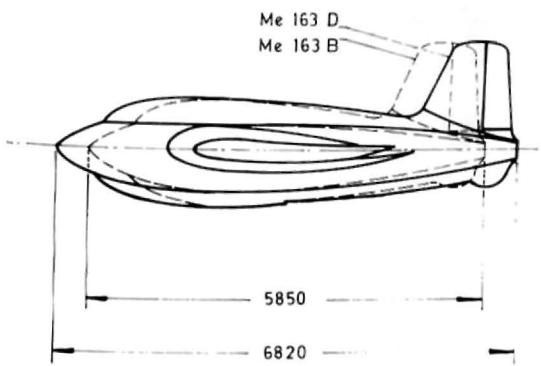


Fig. 62. Project *Me 163 D.* Modification of *Me 163 B* with lengthened fuselage (1942).

5.2 OTHER PROJECT WORK AT DEPARTMENT "L"

NEXT to the interceptor projects, Department "L" worked on other tailless designs of which only partial plans have survived. Project *P 04-107a* of August 26, 1939, a two-place aircraft with two Argus As 10 engines and pusher propellers, was planned as an experimental version of an attack plane or bomber. The *P 04-108* of December 8, 1939, was to be equipped with two Daimler-Benz 601 E engines; project *P 04-114* of May 30, 1941, was again an experimental version for a bomber, but it differed from older projects by its nose-wheel undercarriage and the central rudder on the

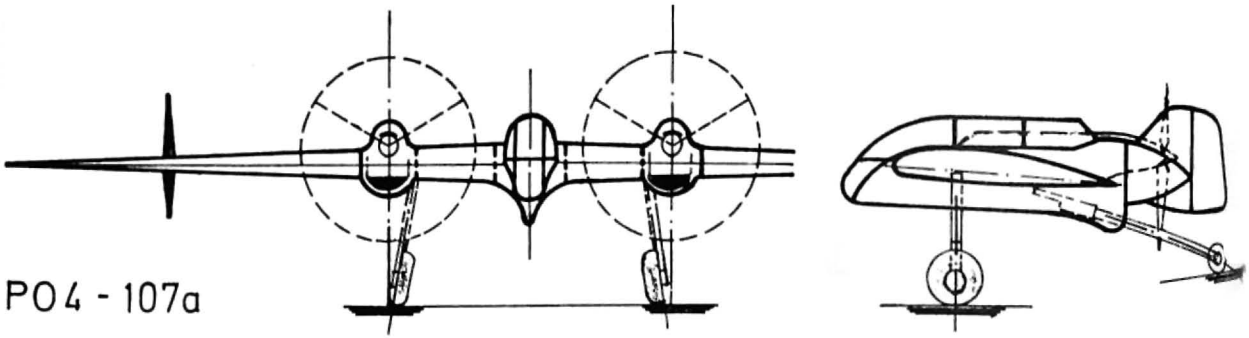


Fig. 63a. *P 04-107a* of a two-engine trainer aircraft (August 1939).

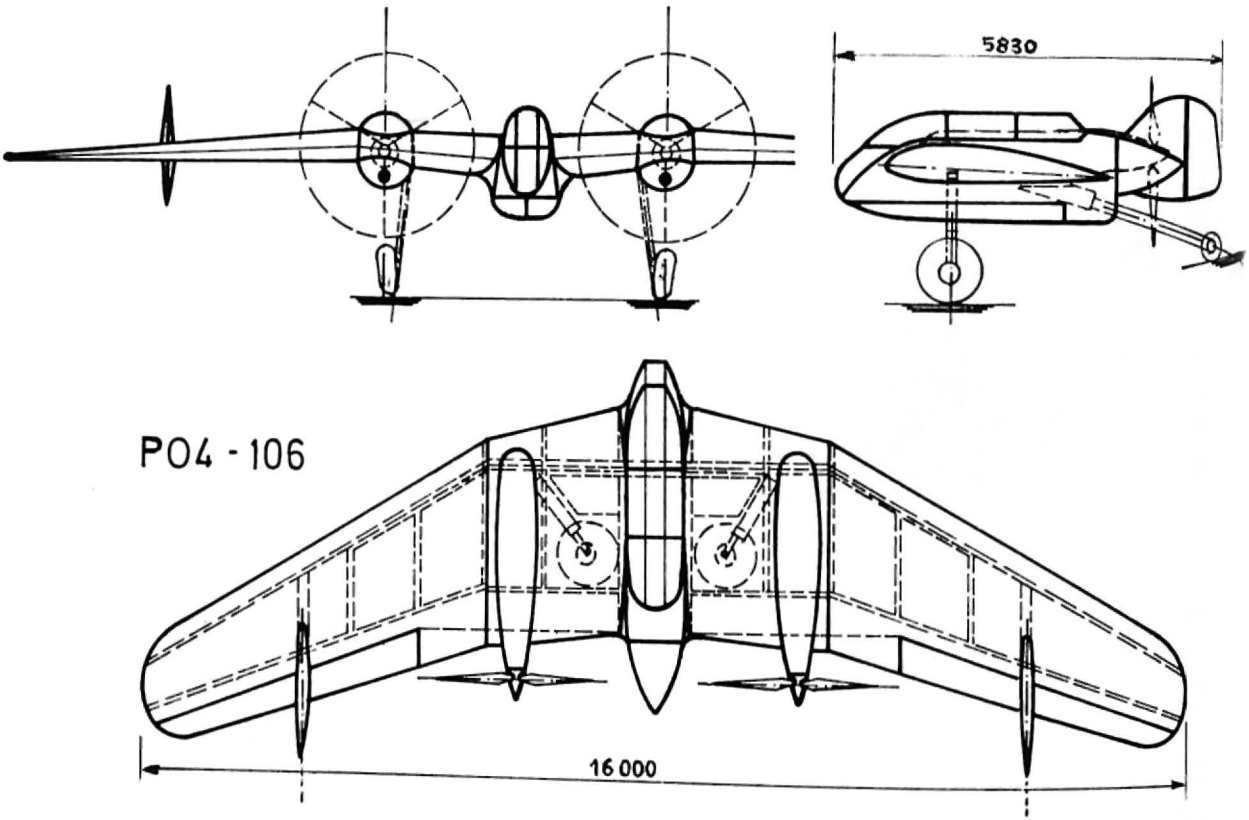


Fig. 63b. *P 04-108* project of a tailless attack plane or high speed bomber (December 1939).

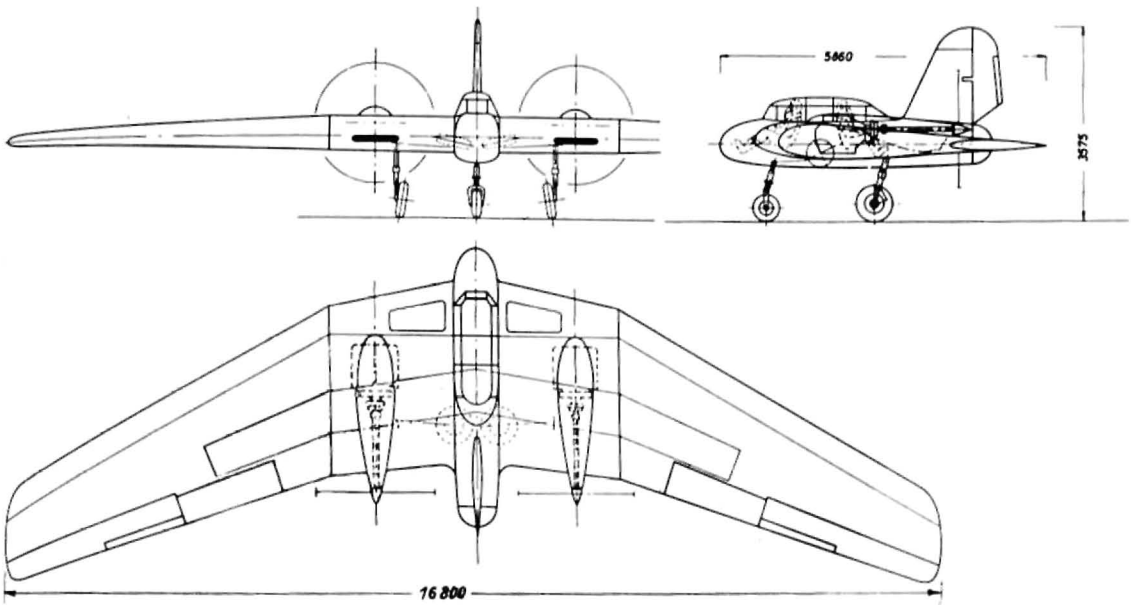


Fig. 63c. Project *P 04-114* of a two-engine trainer (May 1941).

fuselage. Dr. Hermann Wurster was in charge of this design (Fig. 63a-c). Project *P 06* of November 8, 1940 (Fig. 64), which was designed by Rudolf Rentel, was to be a one-place trainer with an As 410 engine, a tractor propeller, and an MG 17. Project *P 08* of September 1, 1941 (Fig. 65), was a four-engine all-wing superbomber with pusher propellers and a wing span of 50.6 m, designed by Dr. Wurster.

Rudolf Rentel was in charge of the project series *P 09*. The first design of this group, dated October 28, 1941, was to be a fighter with two turbojets, while the drawing of May 5, 1942, shows a high speed bomber with two rocket engines mounted side by side (Figs. 66a,b). Project *P 010*, dated November 26, 1941, which was designed by Rentel also, was an attack plane with turbojets and a wingspan of 13.40 m (Fig. 67). Project *P 10* was a high speed bomber designed by Dr. Wurster and dated May 20, 1942 (Fig. 68). The wing was to be low set with a span of 18 m. A piston engine with a pusher propeller was projected. The overall design leaned heavily on the *Me 163*.

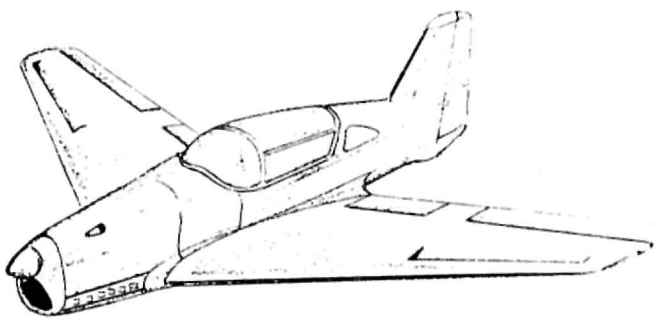


Fig. 64. Project of a one-man trainer with 450 h.p. engine (November 1940).

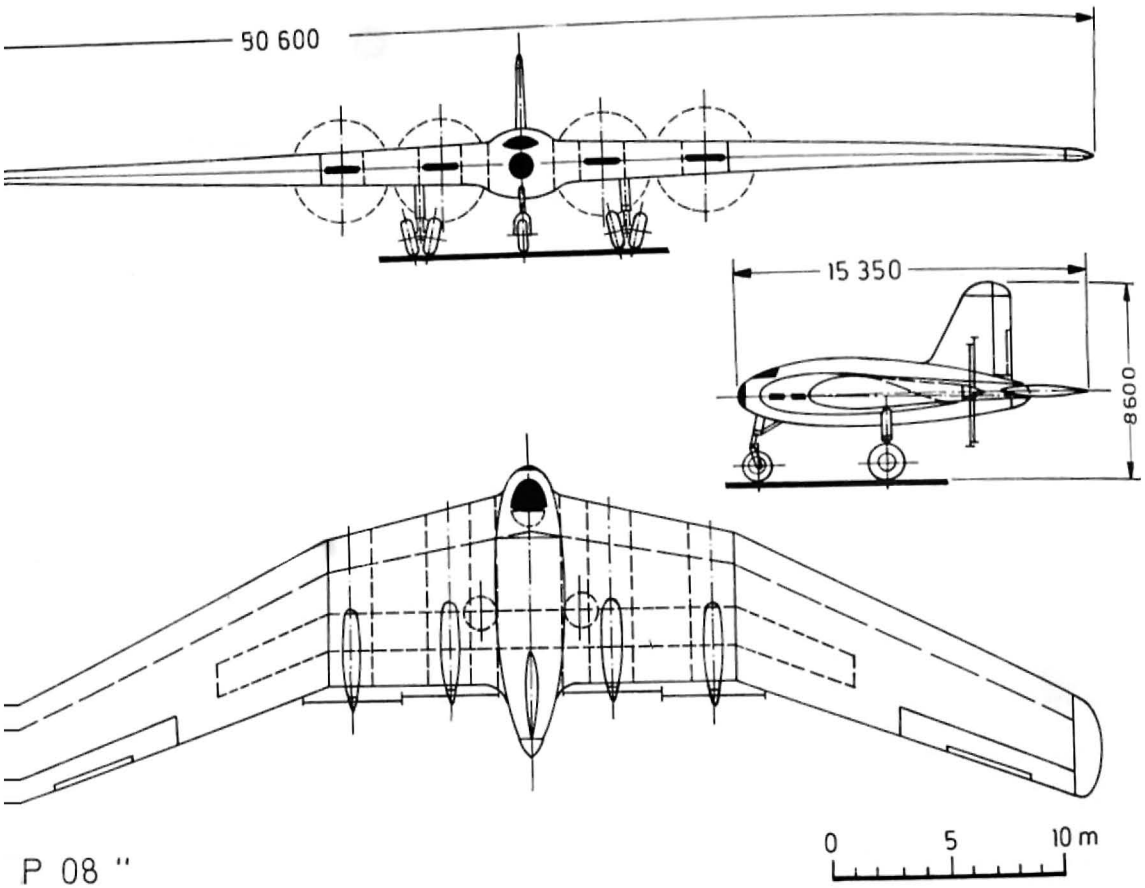


Fig. 65. Project *P 08* for a tailless 4-engine bomber or transport (September 1941).

In the fall of 1942 Stender worked on the design of an attack plane (Fig. 69a,b) which was intended to use parts of the *Me 210* fuselage. This project was originally also named *P 10* but later was designated *Me 265*. Together with the high speed bomber design *Me 329* (Fig. 70), which evolved from the *P 04*, these projects were developed for comparison with the *Me 410* and reached the mock-up stage. A further high speed bomber project, the *P 11* (Fig. 71), was developed by Hendrick. This design was conceived as an all-wing structure with propulsion by two turbojets. The first version of September 13, 1942, was a two-place design (Fig. 71a). The drawing of the second version of December 2, 1942, and the photographs of the model show a change to a single-place design and feature swinging stabilizers which were hinged to the stabilizers of the rudder. They were hydraulically deflected to a horizontal position (Fig. 71b). Since the fuselage of the *P 11* was rather long, it made sense to use the leverage to partly offset the lifting flap moments and therefore to increase the maximum lift coefficients. It was not absolutely essential for this aircraft to be

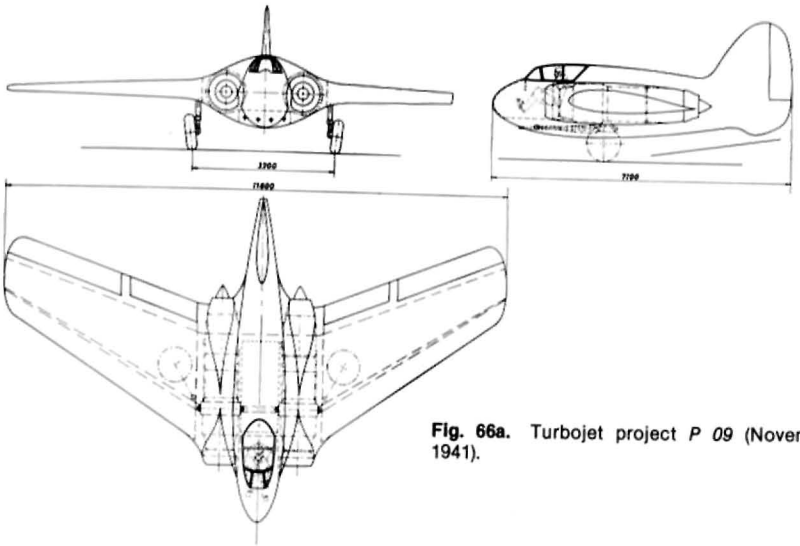


Fig. 66a. Turbojet project *P 09* (November 1941).

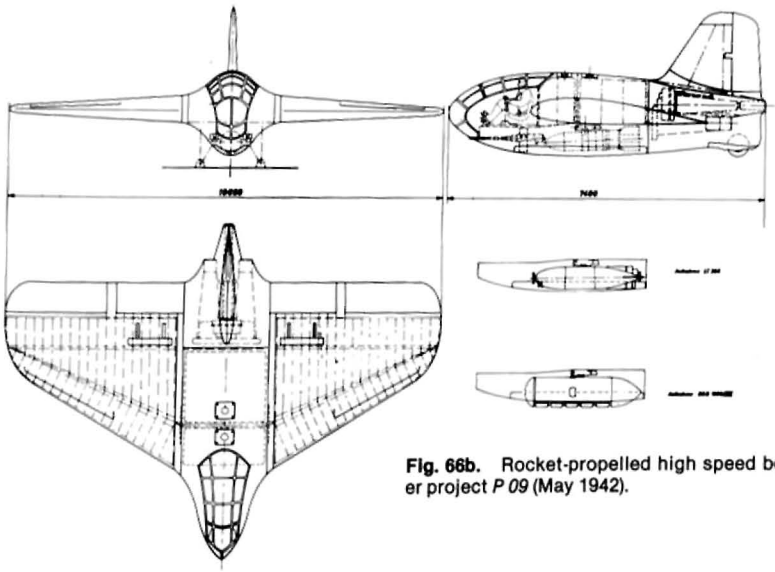


Fig. 66b. Rocket-propelled high speed bomber project *P 09* (May 1942).

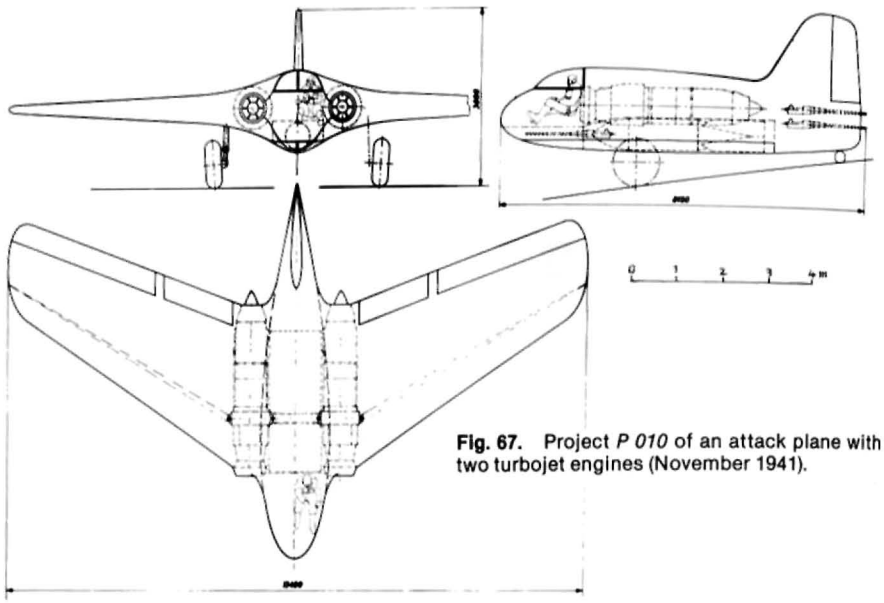


Fig. 67. Project *P 010* of an attack plane with two turbojet engines (November 1941).

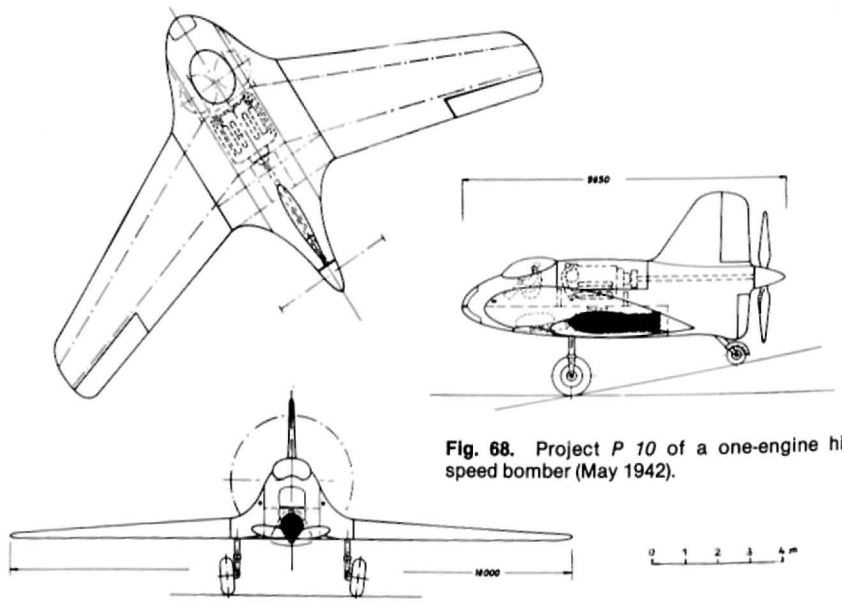


Fig. 68. Project *P 10* of a one-engine high speed bomber (May 1942).

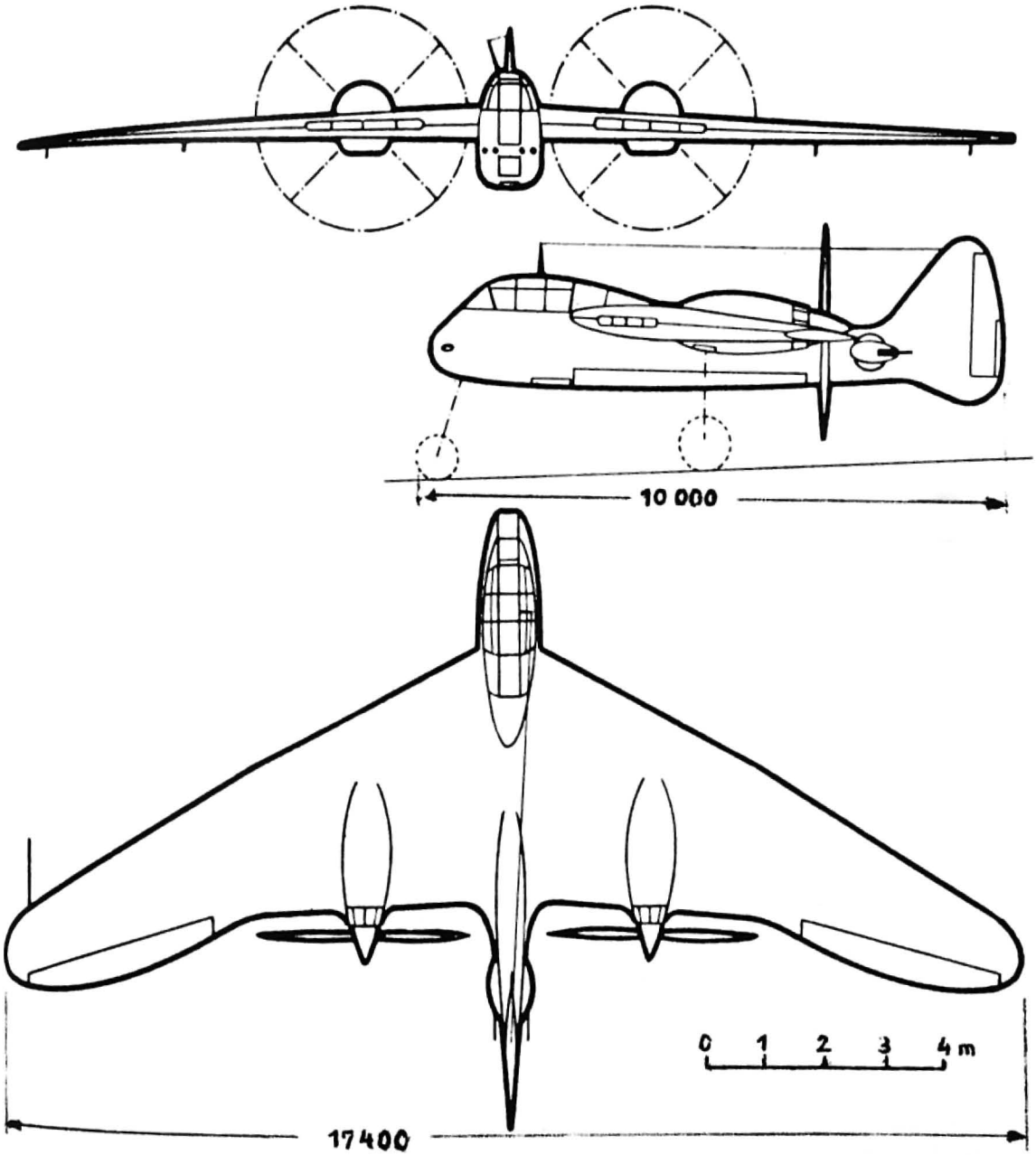


Fig. 69a. Project *Me 265* (from *P 10*) of a two-engine attack plane (1942).

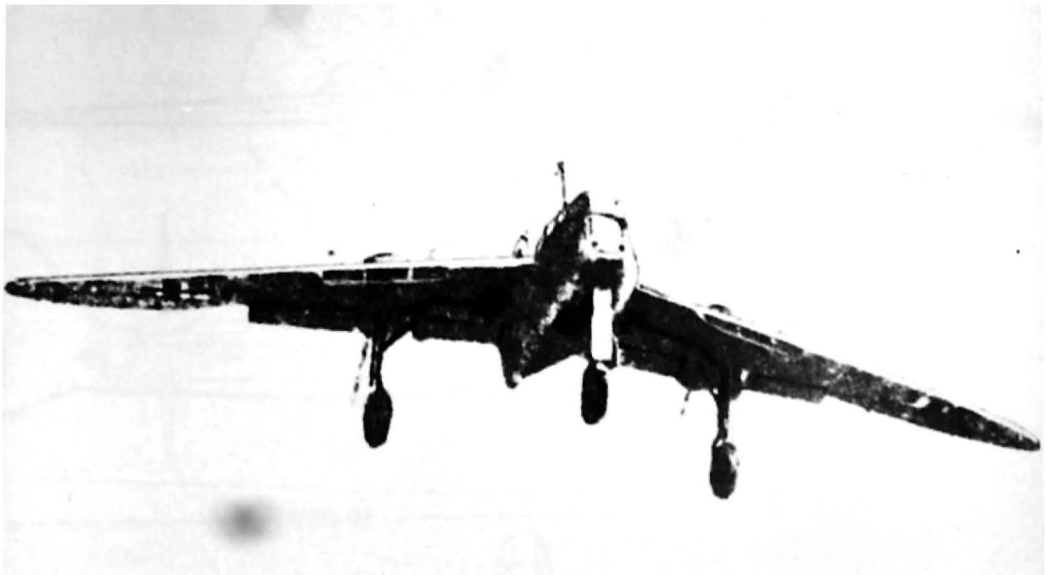


Fig. 69b. Drawing of project *Me 265* in flight.

tailless. Stationary horizontal stabilizers on the fuselage tail had already been tested with wind tunnel models of the *P 01* (see above).

At times Department "L" was also involved in the development of glide bombs, with and without self-propulsion, which were being worked on at different aircraft plants. Very little documentation of this work has survived. We know that in 1940 release experiments with glide bomb *M 09* were carried out and that on May 9, 1941, the first drop of long-distance glide bomb *FG 03* of 420 kg weight was performed. Two samples of this design with a wooden fuselage of 50 cm diameter and a trapezoidal wing area of about 5 m² were built. At the end of the fuselage a double rudder was installed. The remote control equipment had been produced by Siemens Apparate und Maschinenbau A.G. (SAM). A successor of the *Me 110* (*Me 161* or *162*?) was used as the carrier. Heini Dittmar served as remote control pilot. The first release on the airfield near Lagerlechfeld started out very well, but after a while Dittmar lost track of the model. Nevertheless it landed safely in the Lech River meadows, since its center of pressure had been carefully determined in the large wind tunnel in Göttingen. The second release ended with the total loss of the model because of a shift in the center of pressure. A number of reasons prevented continuation of this work.

A surviving drawing of the flight bomb *FG 10* (Fig. 72) of December 20, 1941, actually represents an unmanned and somewhat reduced *Me 163* with automatic controls in the nose, explosives in the center of pressure, and a rocket engine in the tail. The two fuel tanks were installed in front and in back of the explosive charge respectively. The follow-up of this project lay in the hands of Dr. Wurster. All of these projects were carried out by order of the Development Department of the Air Ministry. Building instructions and performance calculations accompanied some of these design proposals.

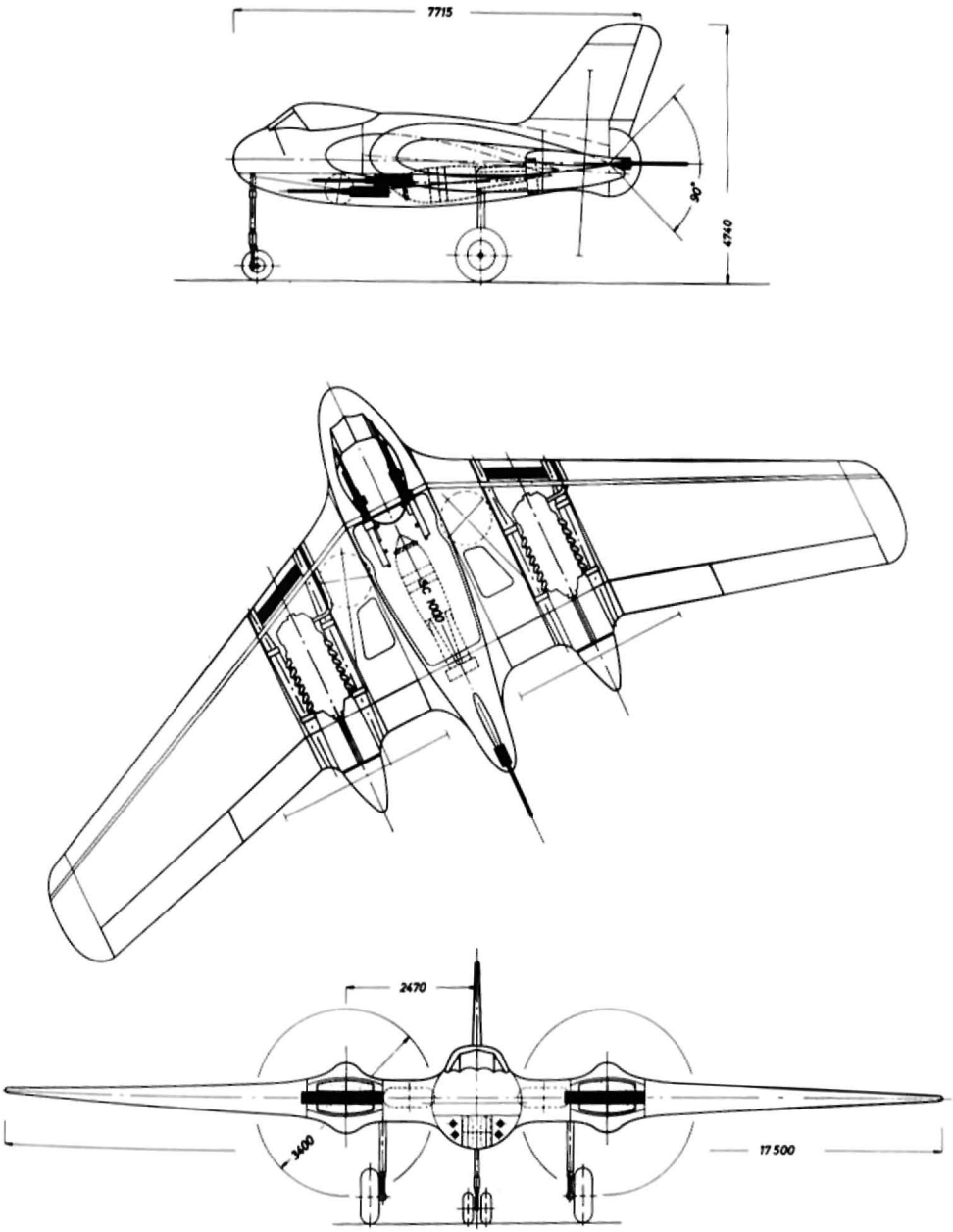


Fig. 70a. Project *Me 329* of a two-engine attack plane (September 1942).

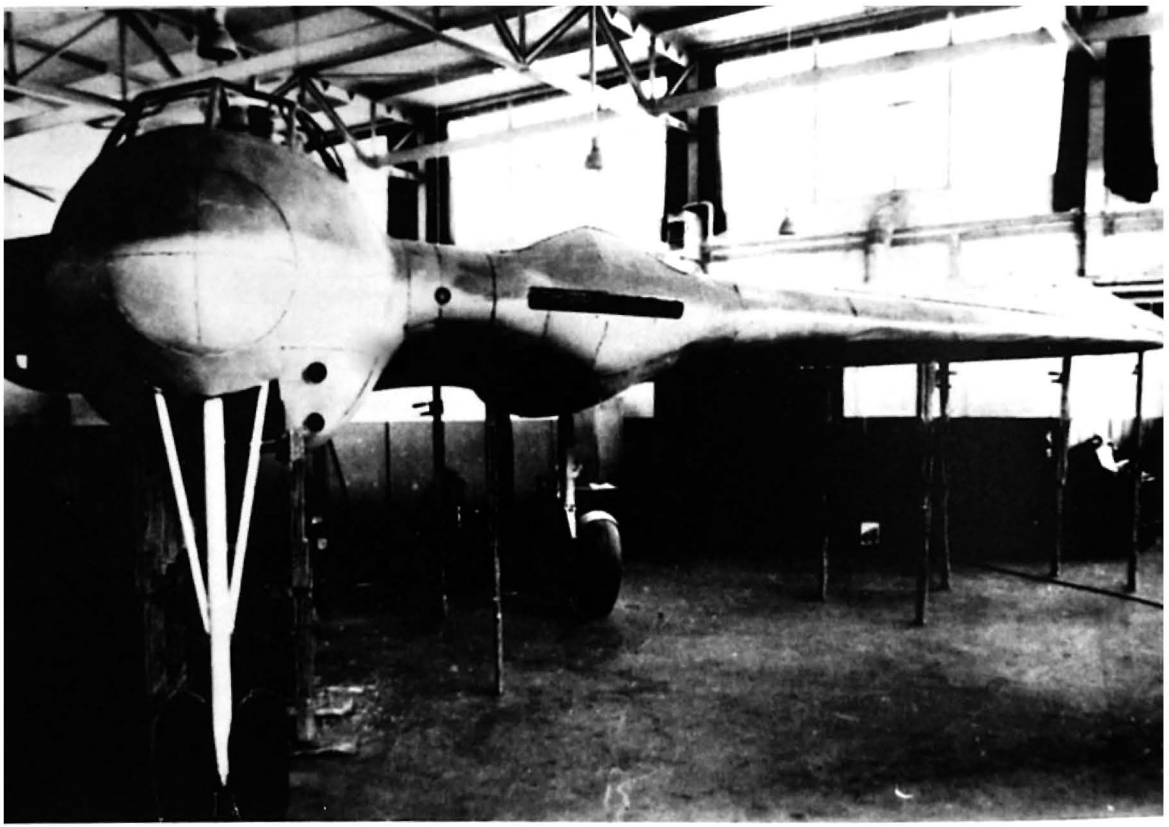
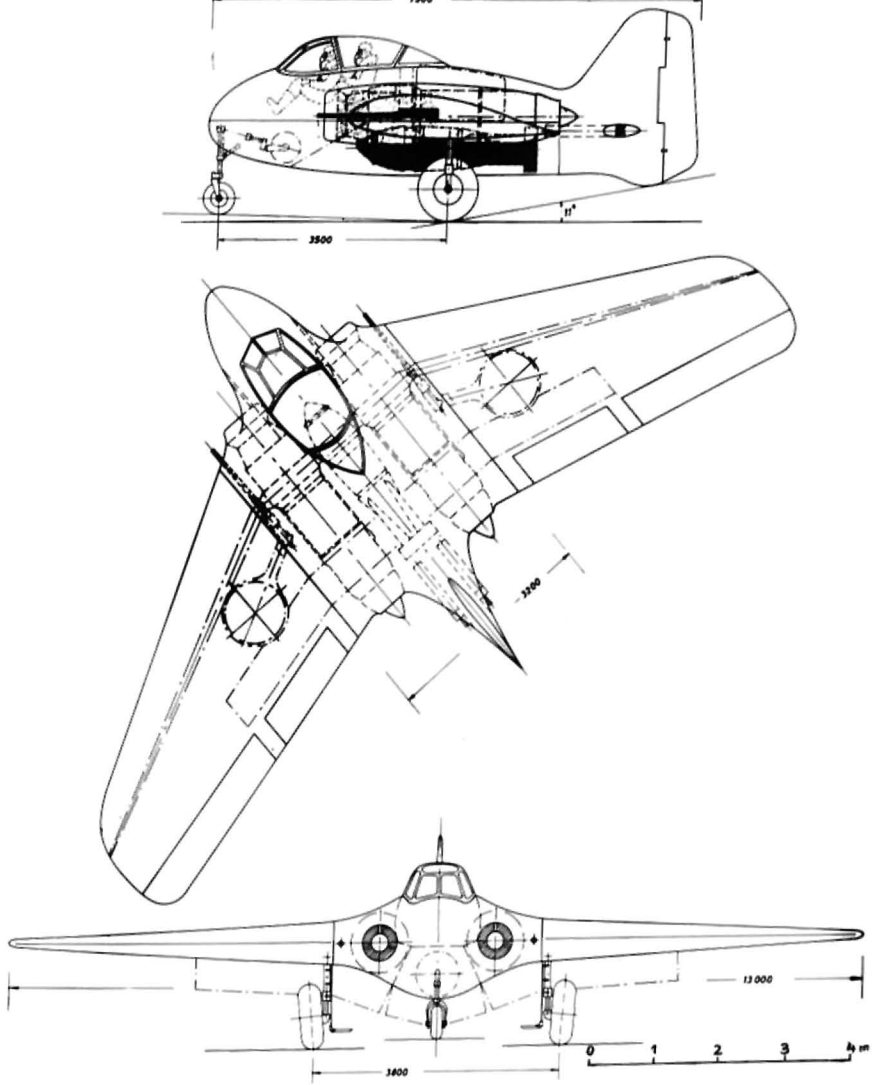


Fig. 70b. Mock-up of *Me 329*. Construction was halted in favor of *Me 410*.



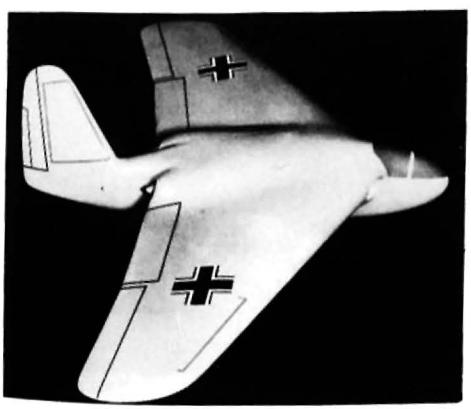


Fig. 71a. Project *P 11* of a two-man high speed bomber with turbojet engines (September 1942).

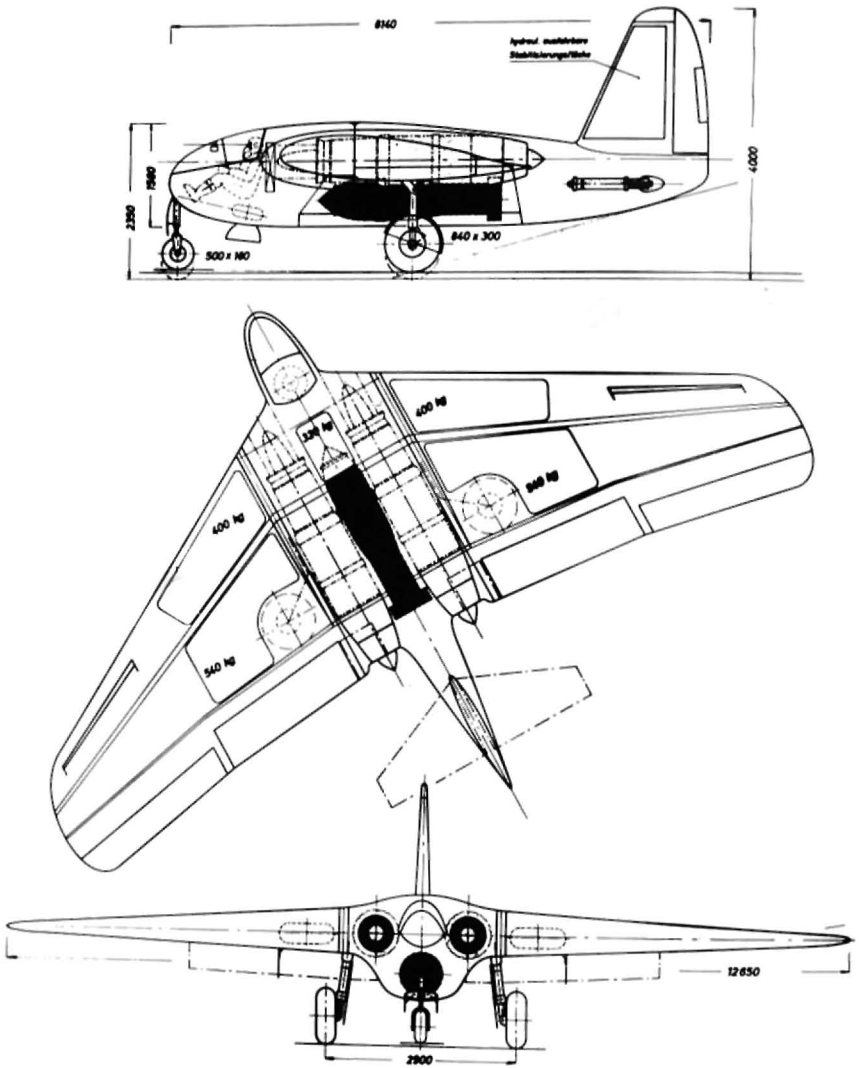
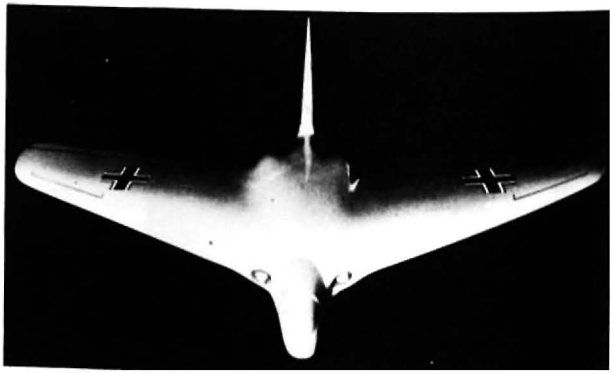


Fig. 71b. Improved project *P 11* of a one-man turbojet high speed bomber (December 1942) layout and model.



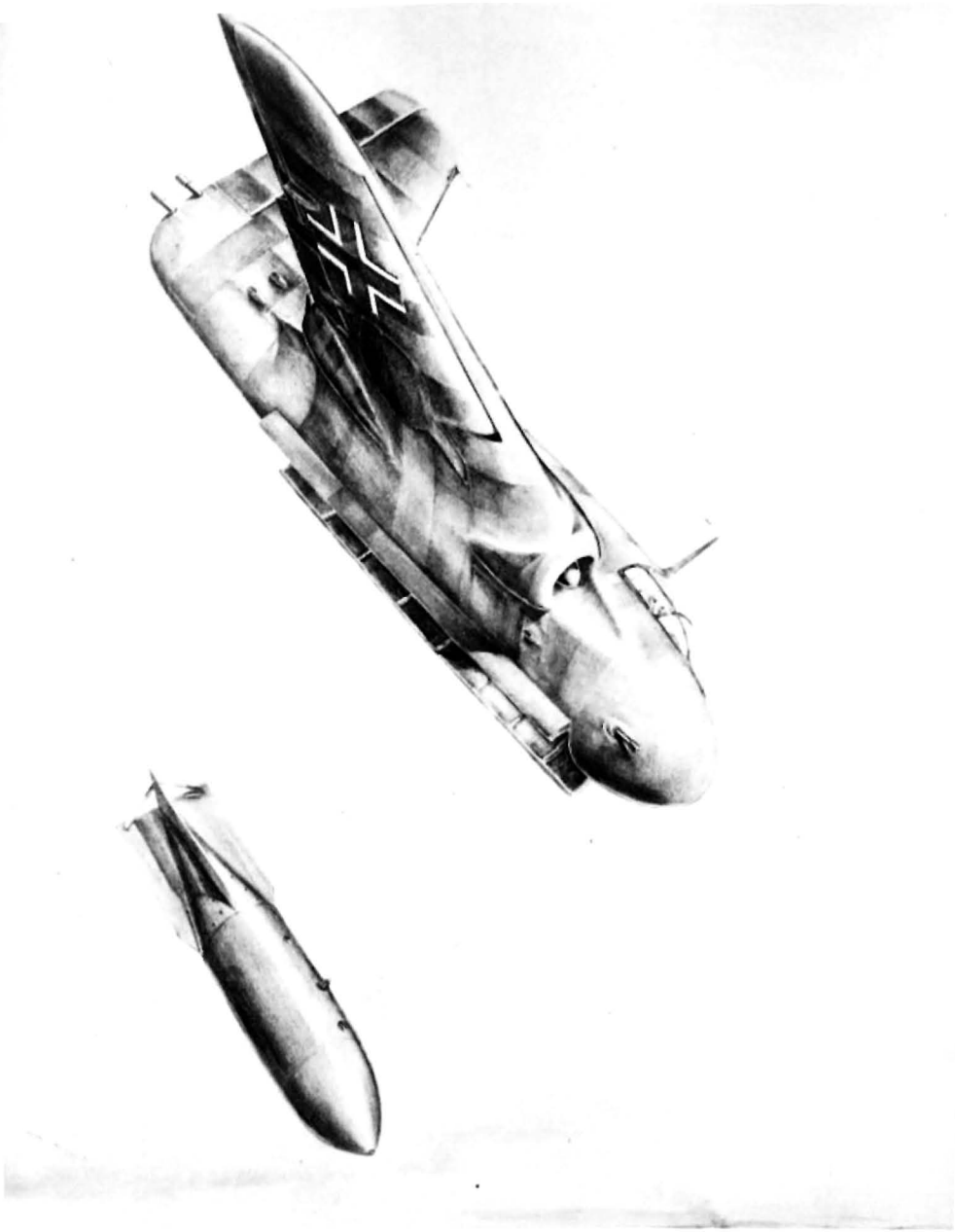


Fig. 71c. Turbojet high speed bomber *P 11* (drawing from December 1942).

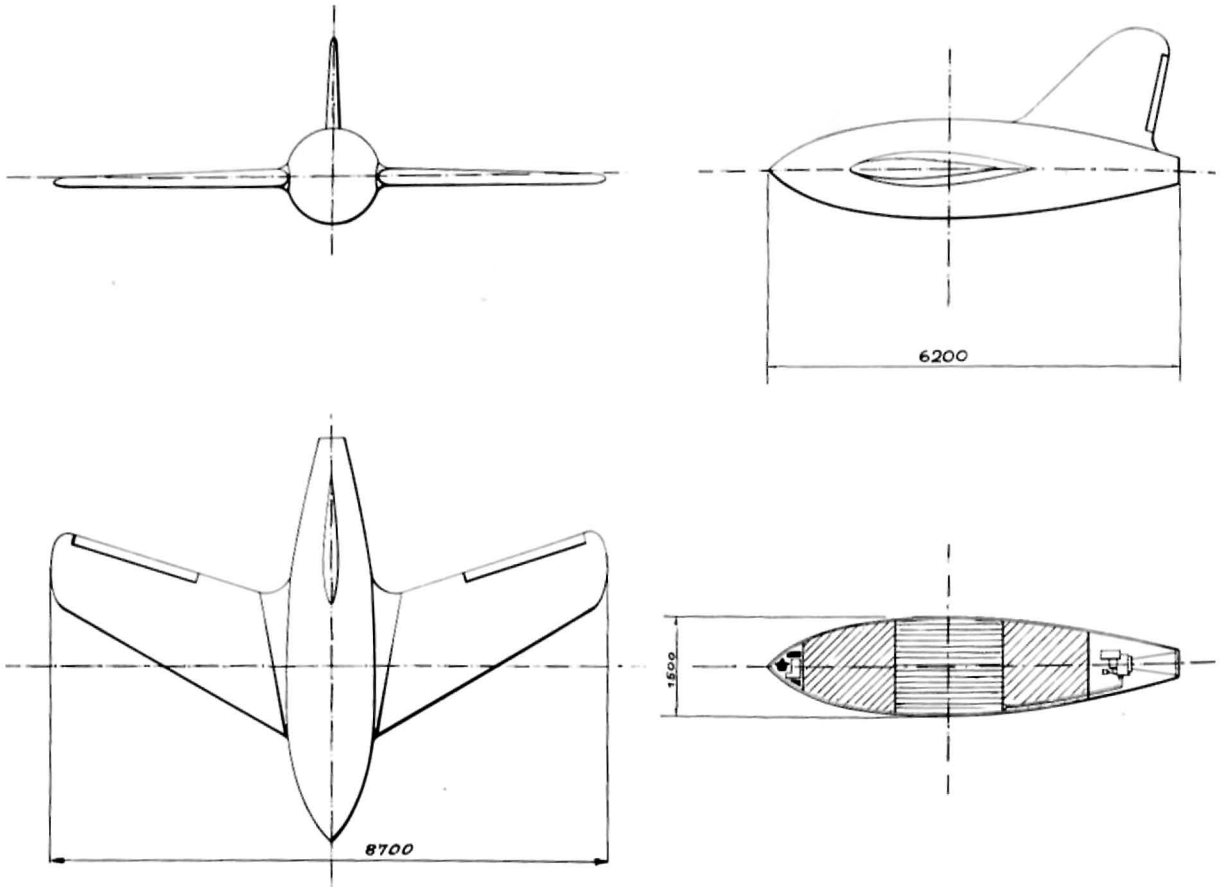


Fig. 72. Project of an unmanned flight bomb with rocket propulsion—*FG 10* (November 1941).

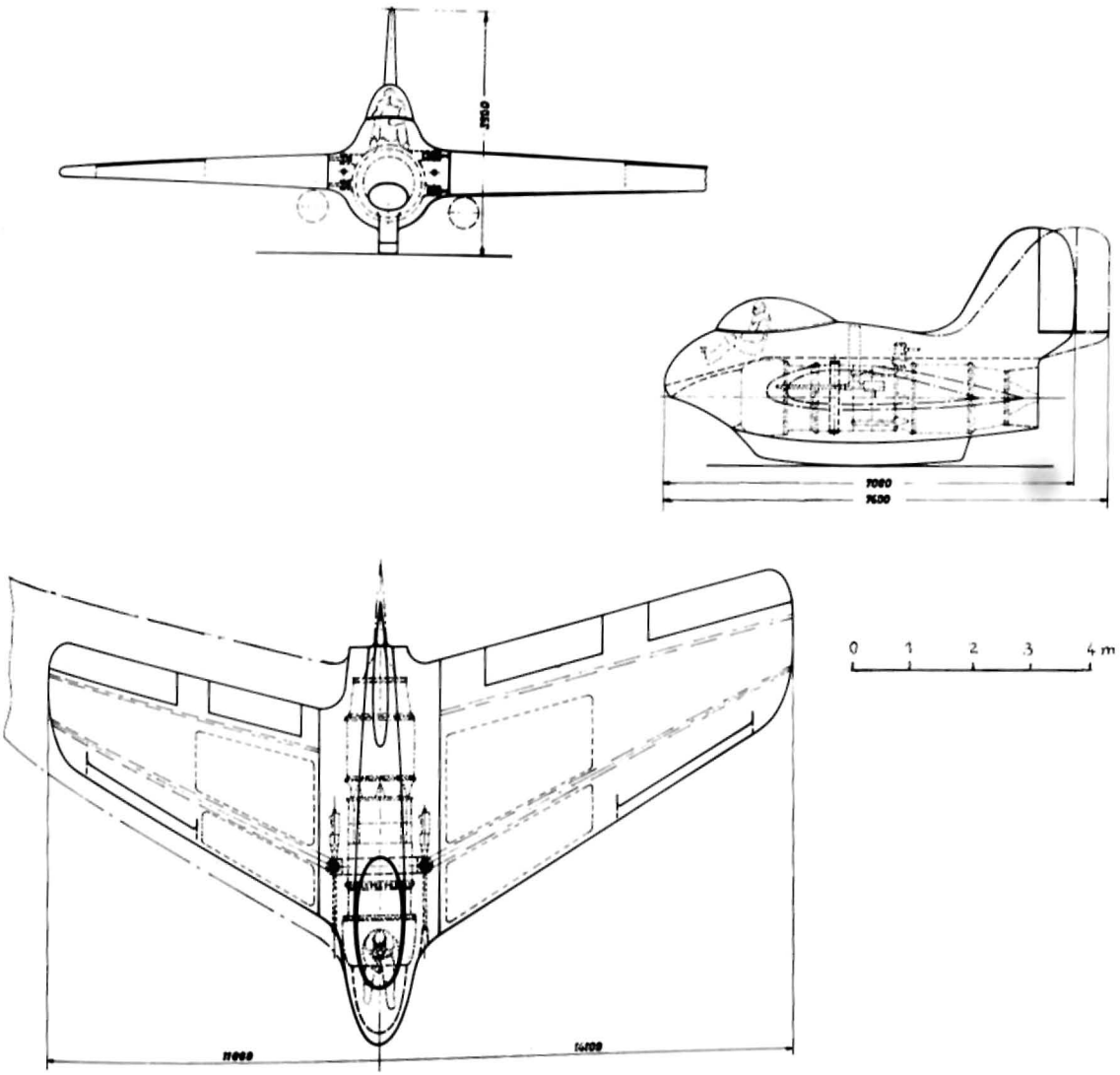


Fig. 73. Two versions of *P 12* (September 1942).

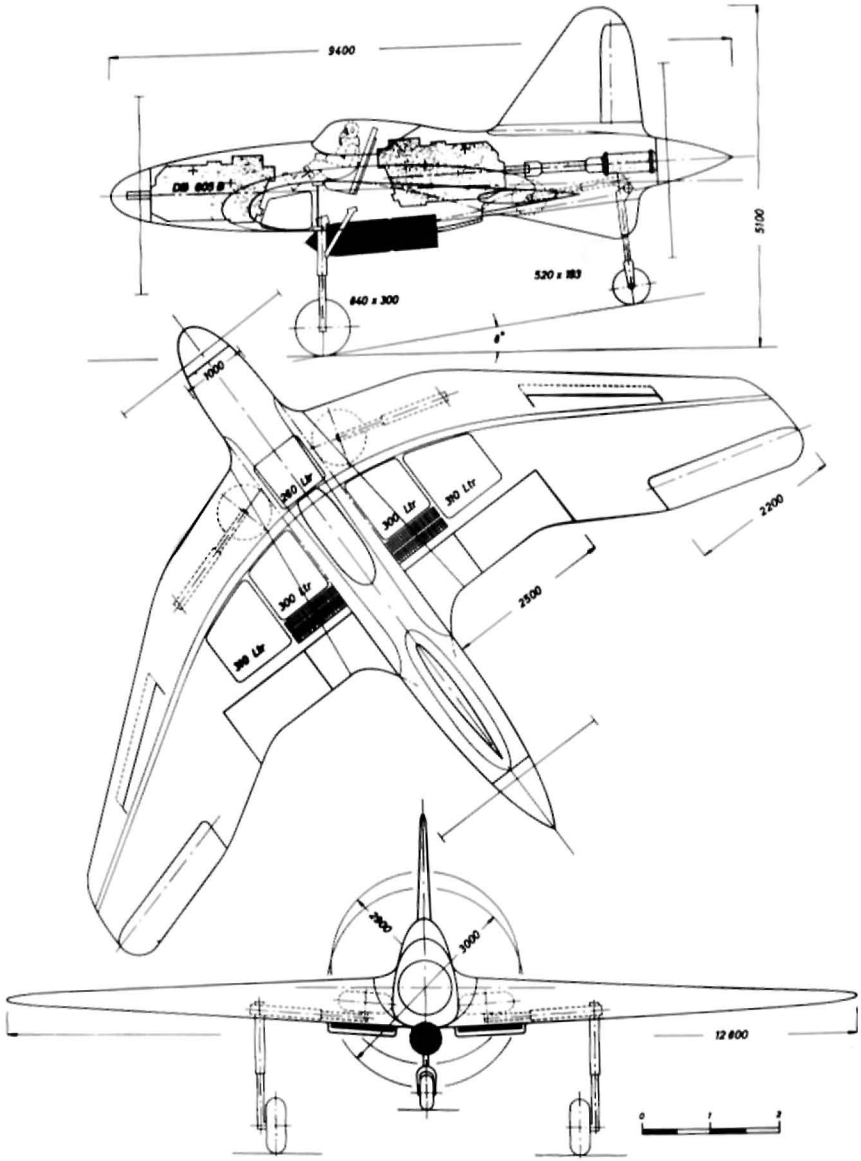


Fig. 74. Project *P 13* of a one-man high speed bomber with engines in tandem arrangement (November 1942).

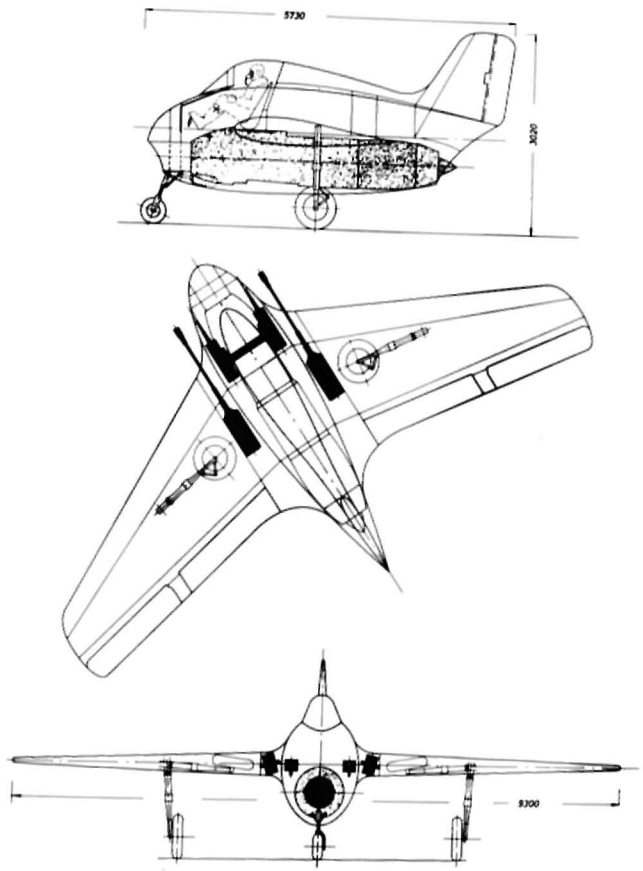


Fig. 75. Project *P 20* of a turbojet fighter, an alternative for the rocket propelled *Me 163 B* (April 1943).

Since the rocket engines proved very unreliable we developed alternate designs powered by piston engines and pusher propellers, similar to the one-engine *P 10* (Fig. 68) and the *P 20* (Fig. 75) of April 16, 1943, with turbojet propulsion. Both designs had a retractable nosewheel undercarriage. On September 30, 1942, Hubert drew up a proposal of 11.0 m and 14.1 m wingspan respectively, using a large turbojet engine (TL 3303). Both these projects bore the designation *P 12* (Fig. 73). A further project by Hubert, dated November 25, 1942, shows a tailless high speed bomber with swept-back wing and two piston engines installed in tandem (tractor and pusher propellers), designated *Li P 13* (Fig. 74). Both these proposals were not connected with my later *P 12* and *P 13* projects.

On April 28, 1943, Department "L" at Messerschmitt was dissolved. After my departure from Messerschmitt a few more proposals of tailless aircraft were prepared, which to some extent were based on my ideas, but I was not personally in-

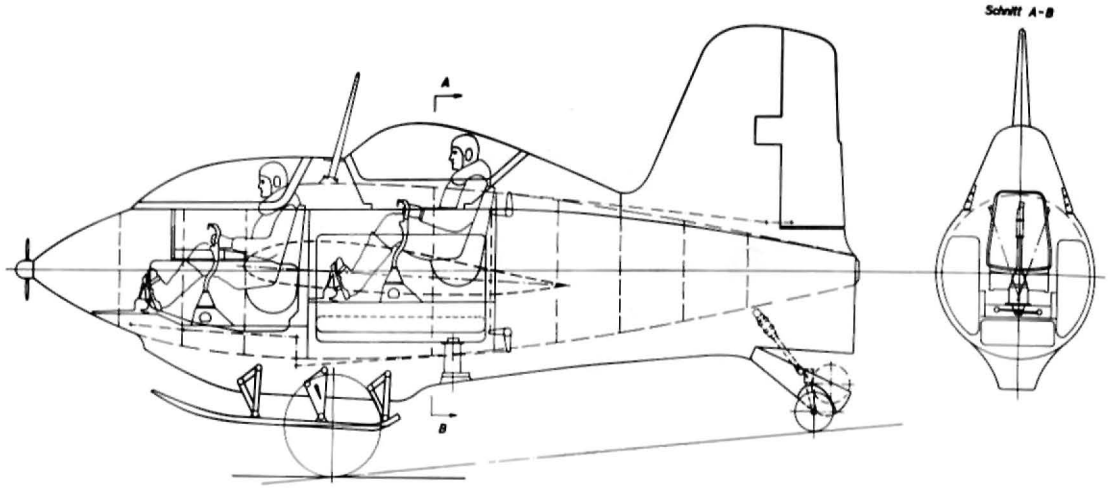


Fig. 76. Two-man trainer glider, *Me 163 S*, a version of the *Me 163 B* (April 1945).

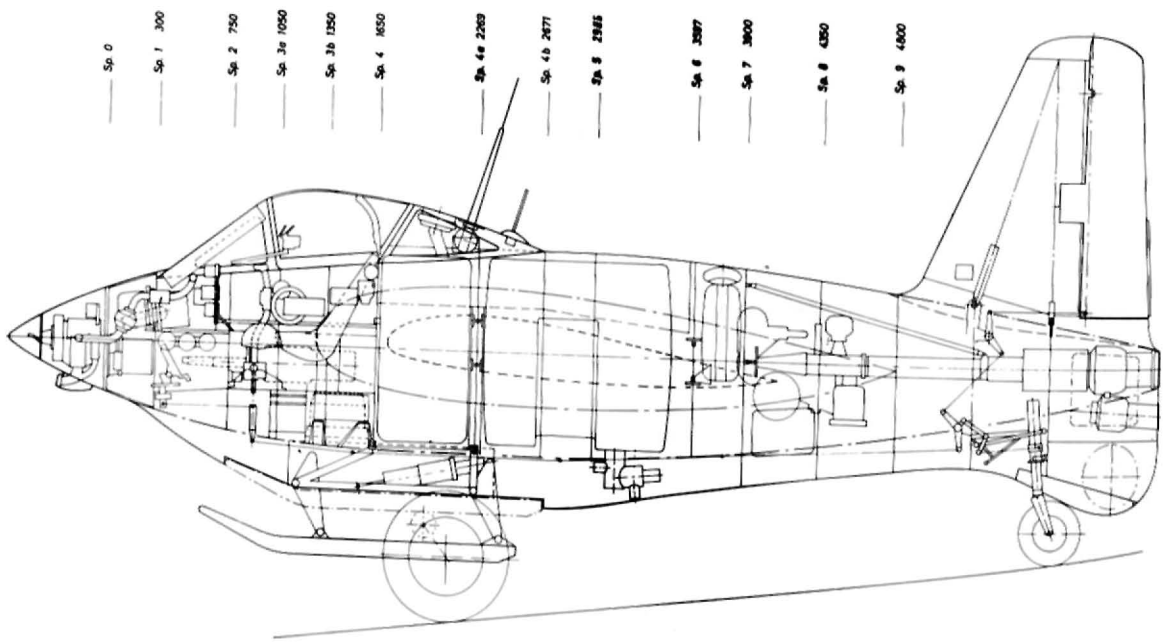


Fig. 77a. Rocket fighter *Me 163 C* (August 18, 1944).

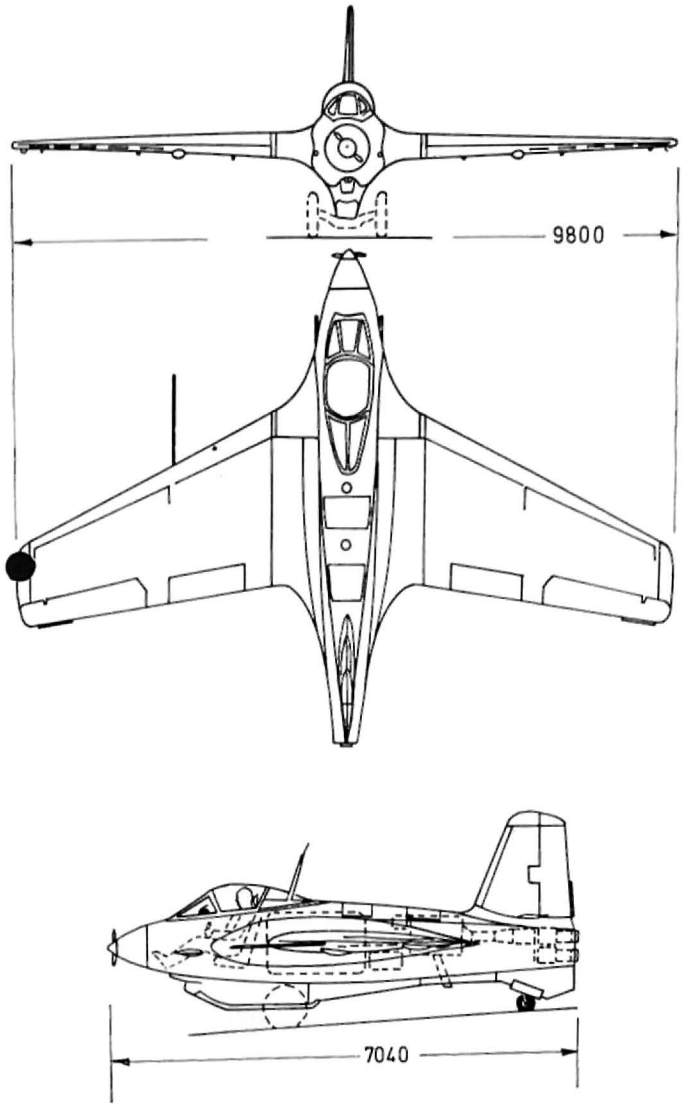


Fig. 77b. Rocket fighter *Me 163 C-1a* (1944). Only a few samples of this version were built.

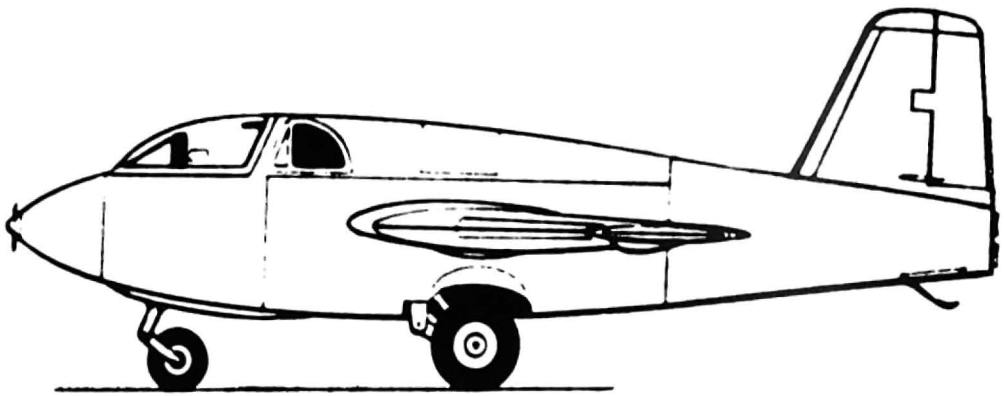


Fig. 78. Rocket fighter *Me 163 D* (1943), predecessor of the *Ju 248–Me 263* (1944).

volved in this work. Further development of the *Me 163 B* was entrusted to the Messerschmitt Project Bureau under the direction of Dr. Voigt. They designed the *Me 163 C* (Fig. 77) with an additional cruise engine and the *Me 163 D* (Fig. 78) with greater range and a retractable nosewheel undercarriage. For a short time a simplified series version was studied by Professor Hertel at Junkers under the designation *Ju 248* (Fig. 79). For promotional purposes it was renamed *Me 263* when this number became available again. A few experimental aircraft were built of each of these versions but none of them was produced in series nor did they reach military action.

At the end of the war a two-place trainer version of the *Me 163* was found at Brandis airfield. A *Me 163 B* had been modified by taking out the rocket engine and installing a raised second cockpit (Fig. 76).

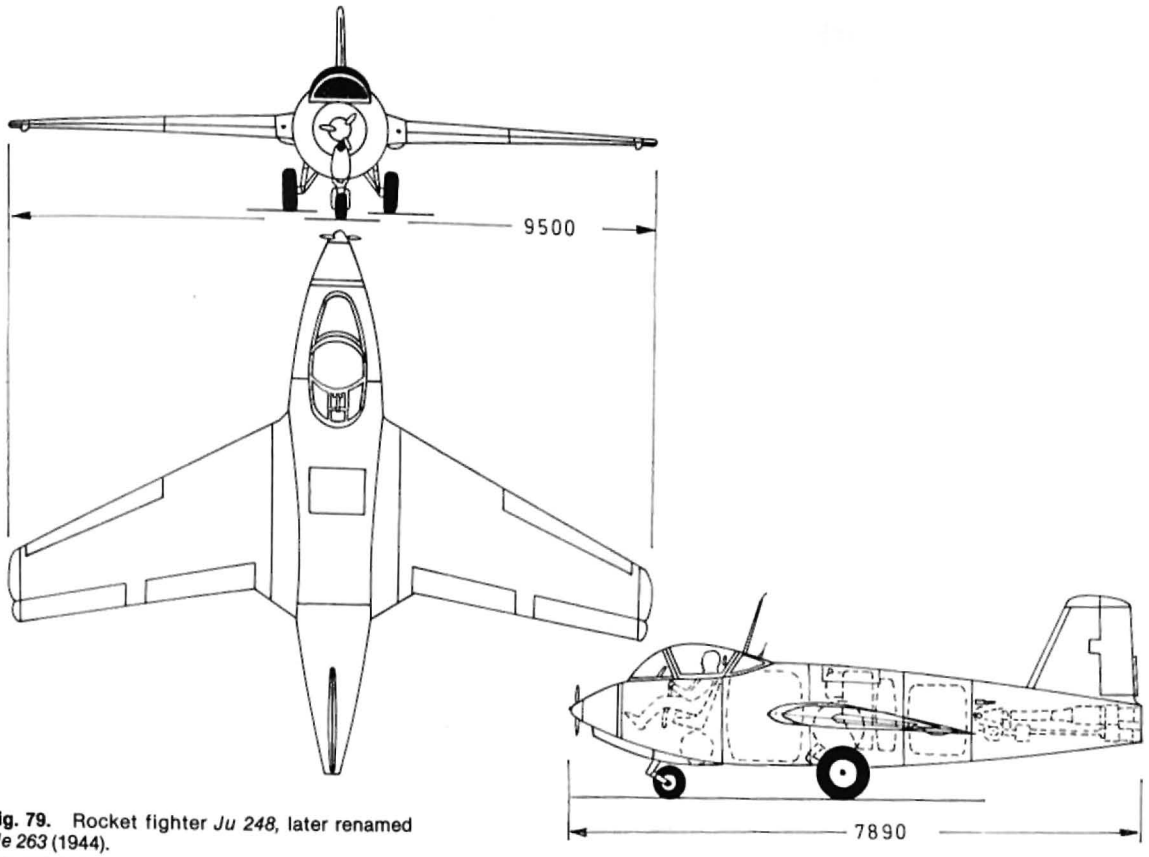
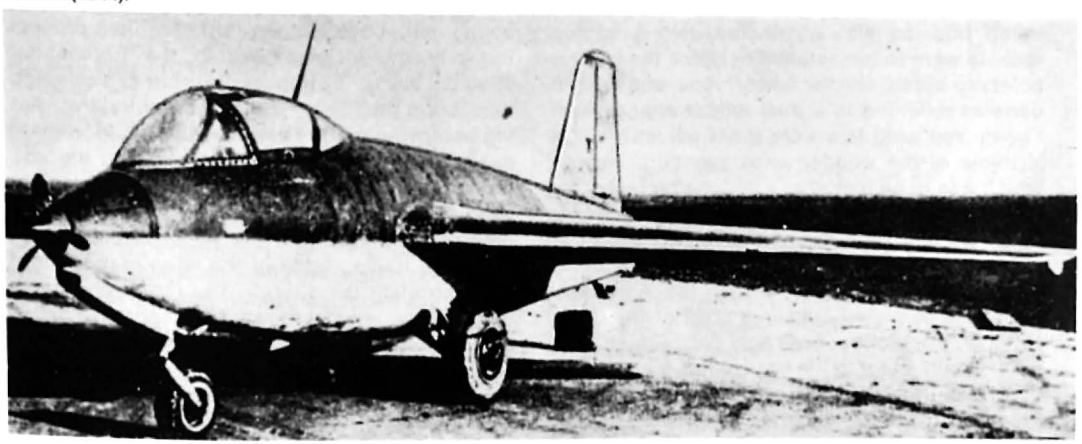


Fig. 79. Rocket fighter *Ju 248*, later renamed *Me 263* (1944).



6 Work at the Aeronautical Research Institute, Vienna (LFW)

ON May 1, 1943, I took over the directorship of the Aeronautic Research Institute, Vienna (LFW—Luftfahrtforschungsanstalt Wien). In addition to continuing the work on the high speed bomber with turbojet propulsion, which we had started in Augsburg, we initiated fundamental research in the development of supersonic aircraft.

The drawing of the high speed bomber *P 11-121* (Fig. 80) of May 17, 1943, shows an extremely wide Delta wing of 10.6 m span and great thickness, which actually can be regarded as an all-wing design. Under the two turbines there was an enclosed space to house a 1000 kg bomb.

Up to December 1943 this project, the turbojet attack plane *P 11-Delta VI* (Fig. 81), progressed to the mock-up stage and the start of construction of a first experimental version (*V 1*). A great number of wind tunnel measurements were performed in Göttingen in connection with this project. The bomb housing was eliminated, two solid fuel rockets were to be installed between the two turbojets to obtain shorter takeoff runs, and the rudder was modified to a dual rudder arrangement. The curved wing tips were made adjustable. The airframe of the wooden experimental prototype, which was to be tested as a glider after takeoff by means of two rockets, was taken out of Vienna when we fled from the approaching Russian armies, but we had to abandon it at the edge of the Autobahn. Hearsay has it that the Americans found the damaged craft in a shed of the Grand Hotel on the Wolfgangsee near Salzburg, Austria, but I cannot attest to the truth of this tale.

Back in 1942, while working on the *Me 163* program, I had studied the problems of supersonic flight. This led me to a Delta wing of very small wingspan and a 60° sweepback angle with very thin wing sections (Fig. 82). We produced a wind tunnel model of this design for the small supersonic tunnel of the AVA. Since the AVA aerodynamicists saw no value in this design, the measurements were put off until 1943-44. Only after I sent one of my engineers to check on the project were the measurements carried out. They included tests at high subsonic and supersonic speeds and were performed in the supersonic wind tunnel. This type of design is now used in the construction of supersonic aircraft.

Next to aerodynamic design we studied the question of economic fuel for supersonic aircraft. In 1912 the Frenchman Lorin had taken out a patent on ramjet propulsion that was far ahead of its time, since this method of propulsion only becomes feasible at velocities near the speed of sound and above. Since ramjet engines produce the pressure increase within the combustion chamber due to the impact pressure at high velocities, Lorin propulsion does not require any rotating or moving parts. Therefore the exterior shape need not have rotational symmetry and the interior of a thick Delta wing of small span may be used as a combustion chamber for this type of propulsion. In addition the jet stream escaping along the trailing edge of the wing may be used for controlling the aircraft. The air enters the interior of the wing through a diffusor. We called this combination "Triebflügel" (thrust wing) (Fig. 83a,b).

The research for the needed burners was carried out by Dr. Schwabl, Vienna, and Dr. Saenger

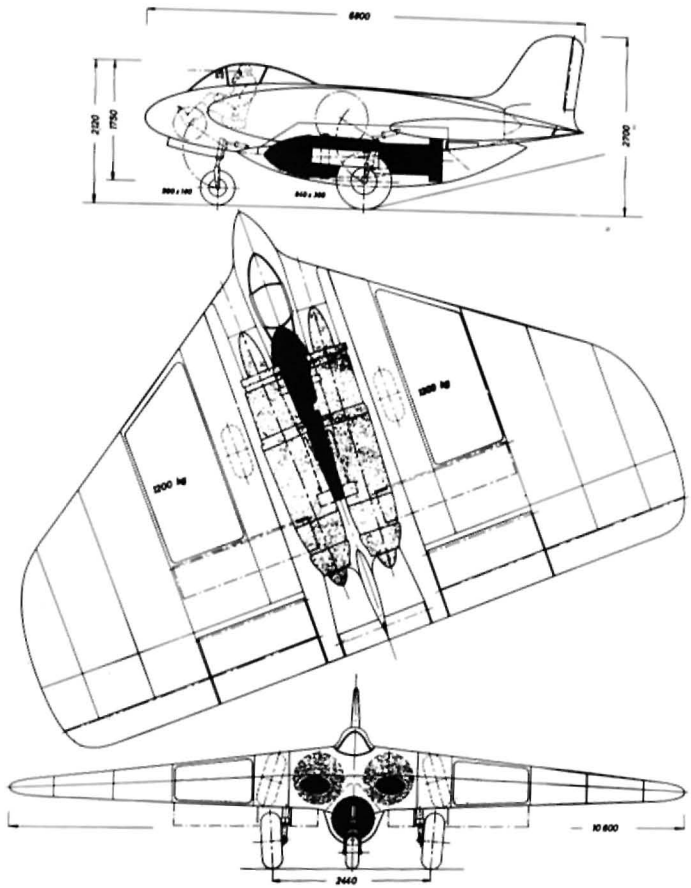


Fig. 80. Improved version *P 11-121* of the turbojet bomber (May 1943).

at the DFS. After tests with Lorin's ramjet-propelled models proved the feasibility of such a power source for aircraft, we proceeded to design the matching experimental aircraft, the *P 12* (Fig. 84). Since ramjet engines do not produce any thrust at zero speed, aircraft equipped with such a propulsion system must be accelerated to the required speed either by means of piggyback towing or by special rocket assist from a launching base. Landing was to be performed on a retractable skid as with the *Me 163*. However, the wind tunnel measurements showed that the air inflow had not yet reached optimal conditions.

This period of intensive activity was cruelly disrupted by an air attack on the LFW in June 1944, which caused the death of 45 members of our team and did great damage to our facilities.

The ever worsening scarcity of liquid fuels led to efforts to use solid fuels in the form of coal dust and other coal products. We developed project *P 13* (Fig. 86), which was actively supported by the Ministry of Armament (Oberst Geist). Test

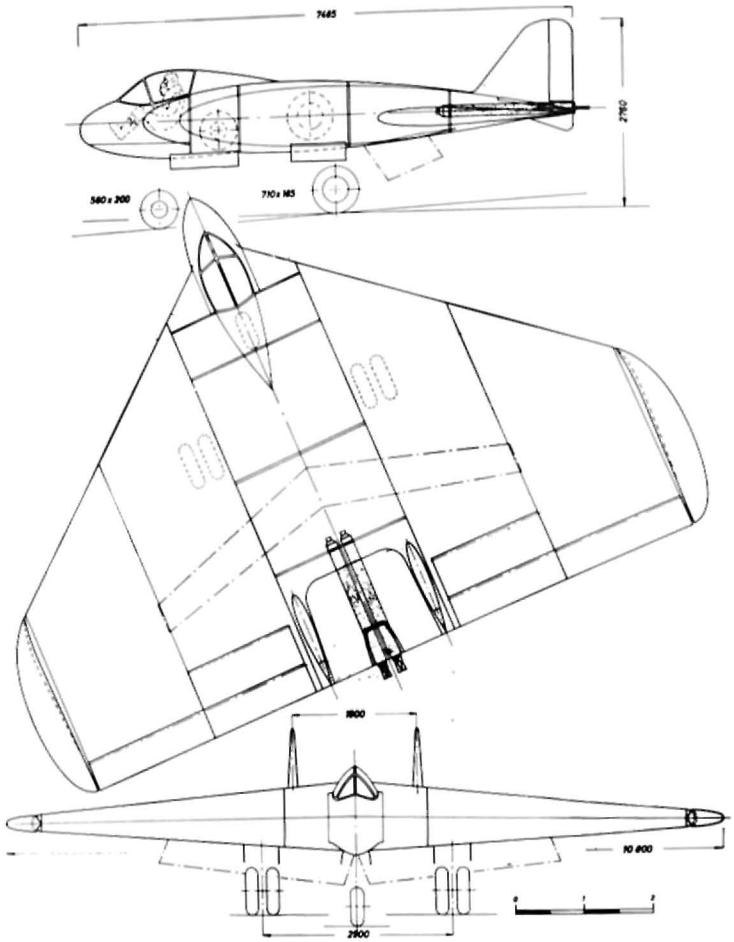
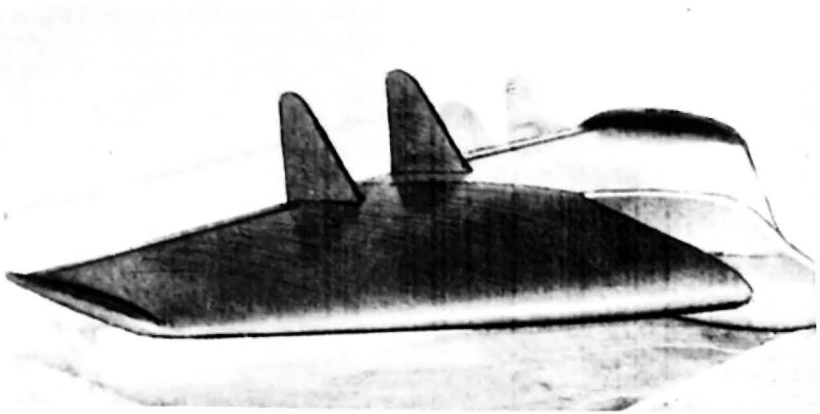
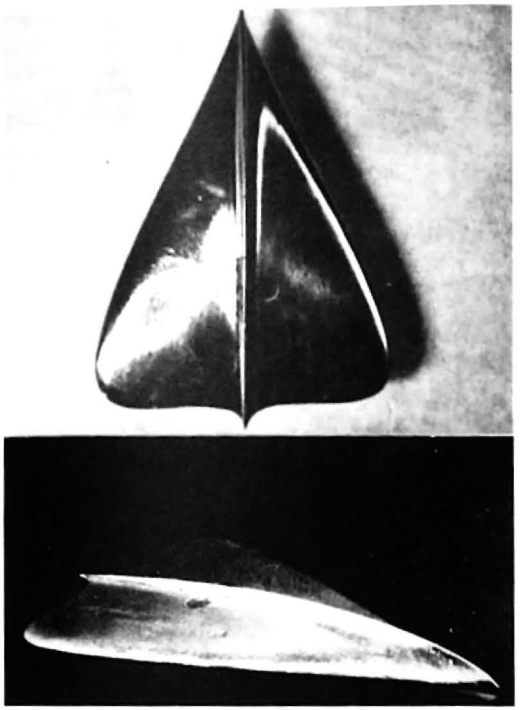


Fig. 81. Project *P 11-Delta VI-V 1* of an experimental all-wing fighter developed from *P 11*. Layout and photograph of model (December 1943).





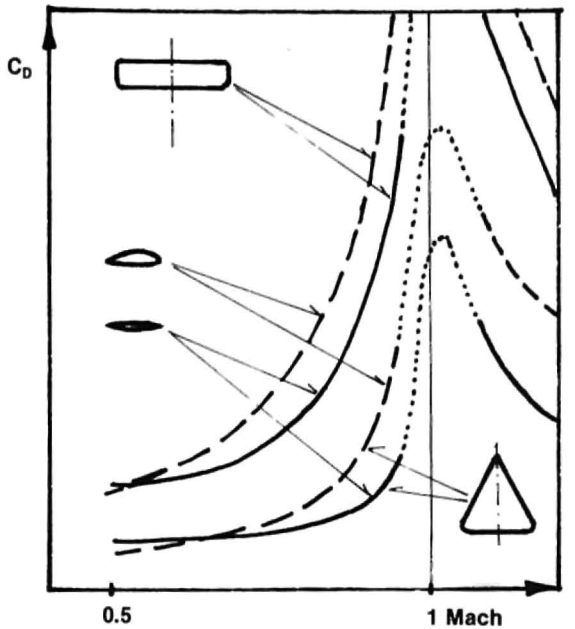
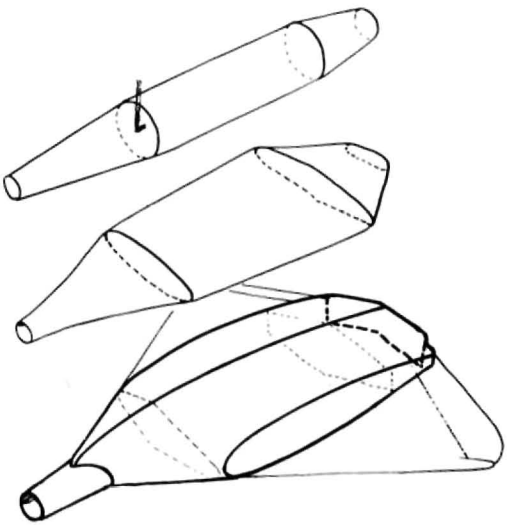


Fig. 82. (*Left*) Supersonic Delta model for wind tunnel tests built in 1942. (*Above*) Function of drag coefficient c_D for a straight wing and a wing with large angle of sweepback.



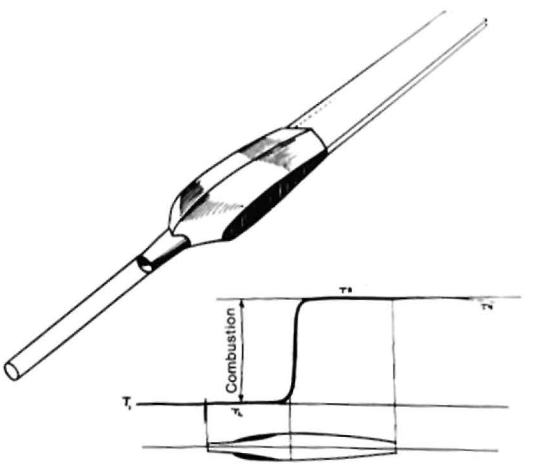


Fig. 83. Ramjet engine: (*Left*) development of a thrust wing from a cylindrical engine; (*Right*) gas expansion with increase of temperature (combustion).

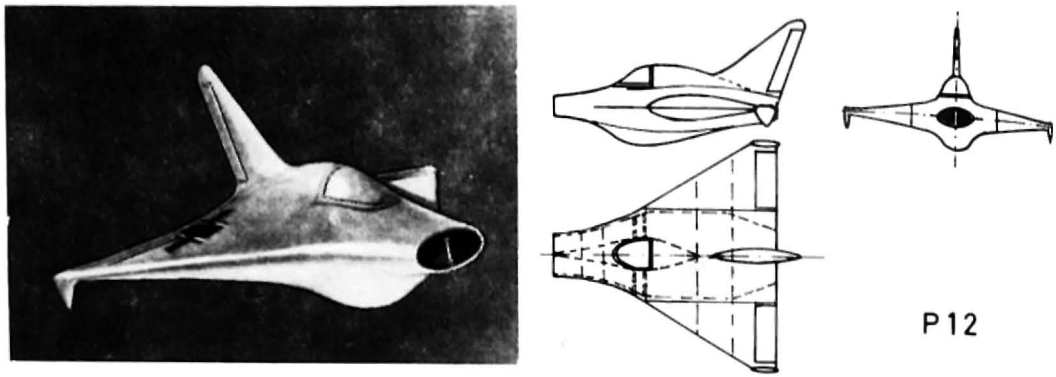


Fig. 84. Project *P 12:* (*Above left*) layout (reconstruction); (*Right*) photograph of model; (*Left*) sketch of Lorin propulsion system.

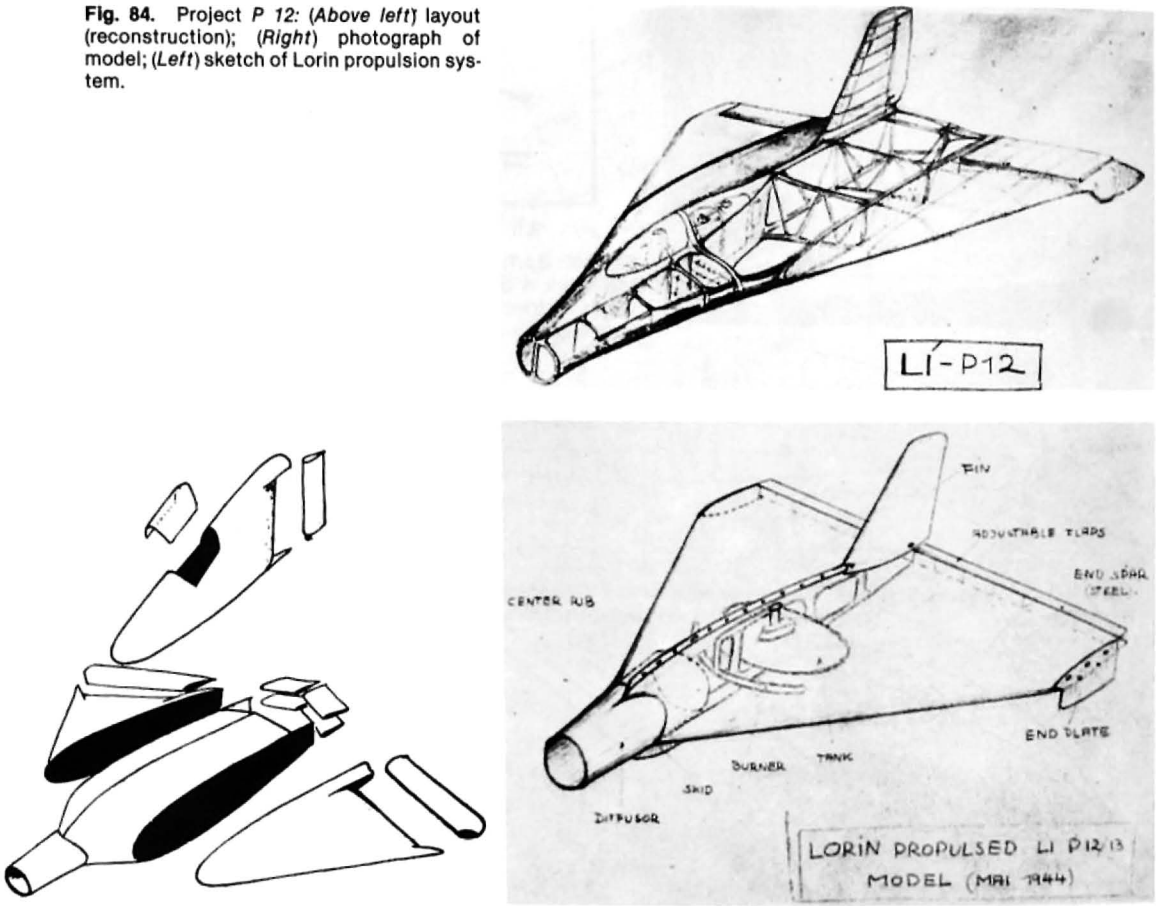


Fig. 85. Sketch of free-flight model *Li P 12/13* of May 1944 and schematic drawing of development toward *P 13.*

flights of a free-flight model of a *P 12/13* (Fig. 85) at the Spitzerberg near Vienna in May 1944 were very successful.

Admittedly this project of a Delta wing of very low aspect ratio and with the location of the cockpit on top of a wing that had been converted into a combustion chamber was rather unusual and there loomed the possibility of flight attitudes which might have to be mastered by special procedures. However, wind tunnel and free-flight model tests did not reveal any especially problematical characteristics. We therefore deemed it practical to start construction of an experimental, manned, powered craft of this design (scale 1:1).

The difficult military situation demanded the drafting of many of the remaining civilian employees for service in the "Volkssturm" (people's army), which was regarded by the powers-that-be as the last line of defense. This meant that the aeronautical engineering students also had to join. Only work of highest priority rating could protect these students from being drafted. Aeronautical students of the Institutes of Technology of Darmstadt and Munich approached me in the hope of obtaining work in connection with the *P 13*. Since the end of the war obviously was imminent anyway. I created the project of a wooden flying-glider version of the *P 13*, which the students were to build under the direction of my assistant, Heinemann, in a hangar of the small airfield in Prien on the Chiemsee. The students designated this project *D 33* (Darmstadt 33) which was later changed to *DM 1* (Darmstadt-München 1) (Fig. 87). We succeeded in obtaining deferment for the students. The *DM 1* was almost completed when the war ended and the Prien airfield was occupied by the American forces. In response to the suggestion of Prof. Theodor von Kármàn the project was completed under U.S. direction. When Col. Charles A. Lindbergh, the famous transatlantic flyer, came to Germany on an inspection tour after the war, the *DM 1* was shown to him, albeit as a design of the student group without mentioning my name. In the corresponding paragraph in Lindbergh's book, *The Wartime Journals of Charles A. Lindbergh* (New York: Harcourt Brace Jovanovich, 1970, pp. 973 ff), he commented:

> [Kracht] thinks the Lorin, or ram jet, may be used for long-range, high-speed flying—transatlantic, for instance—with track launching. . . . The Heinemann flying-wing development, which was being carried on at the D.F.S., was designed to use coal for fuel. (Because of oil shortage. "Would have preferred to use gasoline.") With this they hoped to obtain 1,200–1,300 kilometers per hour with a ram jet. Piggyback launching.

Figure 88 shows an interceptor fighter version of the *P 13* (later named *P 13a*), which was to be constructed of metal with a ramjet and two auxiliary rockets for takeoff located on each side of the ramjet. For a short time, series production of this design was planned.

In July 1944 we designed glide bomb *GB 3 L* (Fig. 89) which closely resembled the *P 13a*. A ramjet of 6 m length which was to burn 105 kg of lignite coal dust drenched with paraffin was to be fitted with a Delta wing of Nipolite and a rudder of the same material. The bomb was to be launched from an airplane. Because of the overload of work this project could not be pursued.

Another *P 13* version, the *P 13b*, had a hexagonal combustion chamber. In this project the cockpit was to be located in front of the wing and a dual rudder replaced the former single one. In the interior of the wing a coal container of heat-resistant ceramic material was to be centrally installed and could be refilled from above. We did not carry out any tests with this arrangement, which was designed in December 1944 (Fig. 90).

In the last months of the war we worked on a project for a turbojet, the *P 14*. Its design was based on the idea that on a Delta wing with turbojet propulsion very thin profiles may be used. Only a demonstration model of this project survives (Fig. 91). This design, that even today looks very modern, has the typical characteristics of an aircraft laid out for high subsonic speeds: a large angle of sweepback, low aspect ratio, profile thickness of only 6 percent, and relatively low wing loading. In such a design the "critical Mach number," characterized by a shock wave which causes a steep rise in drag, moves closer to Mach 1.0.

On the occasion of Colonel Knemeyer's [from the Air Ministry] visit in Vienna we dis-

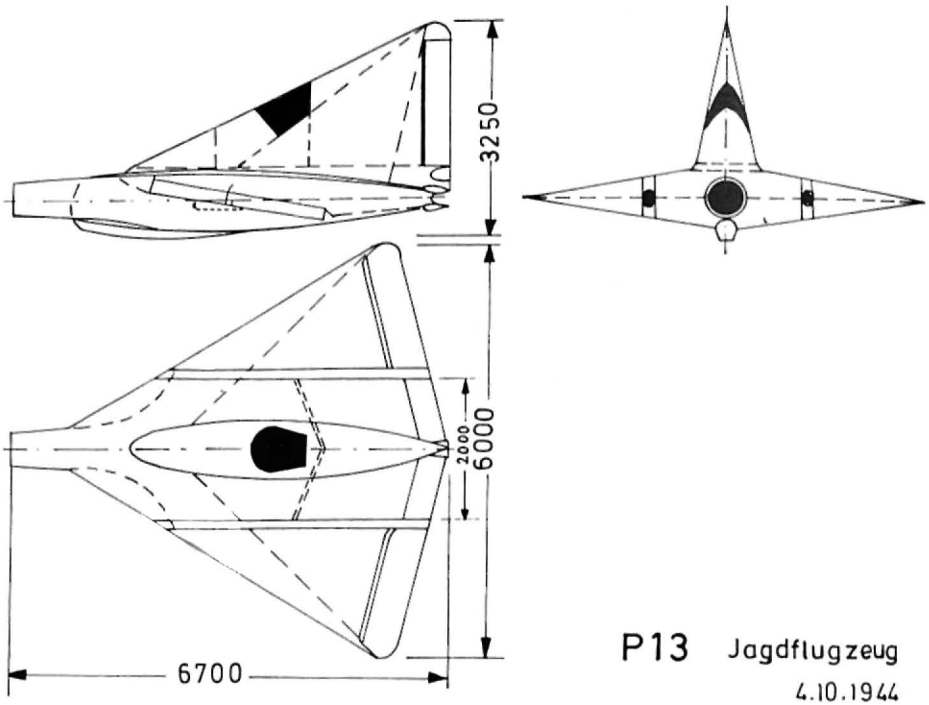
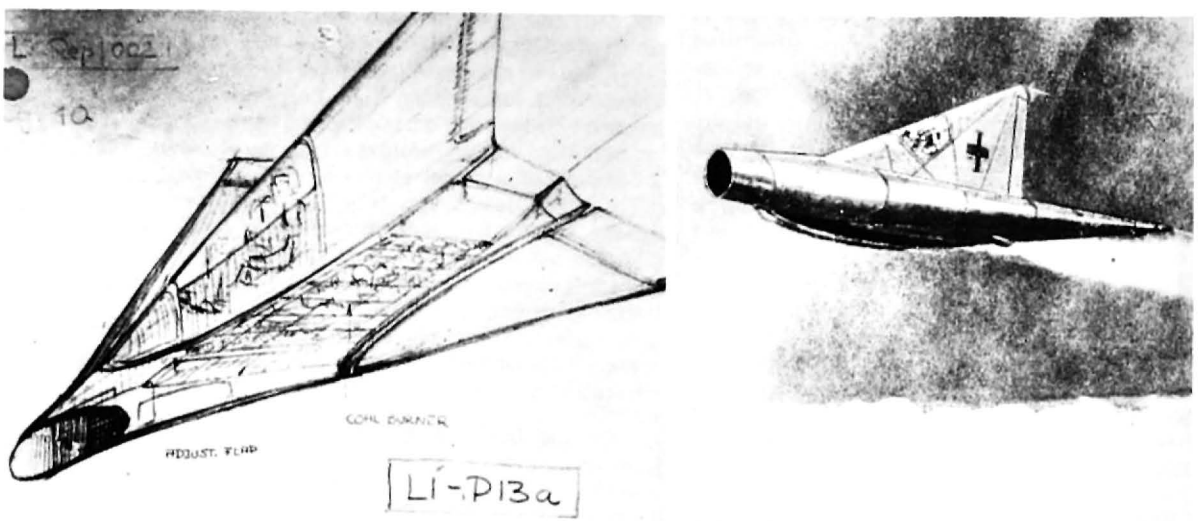
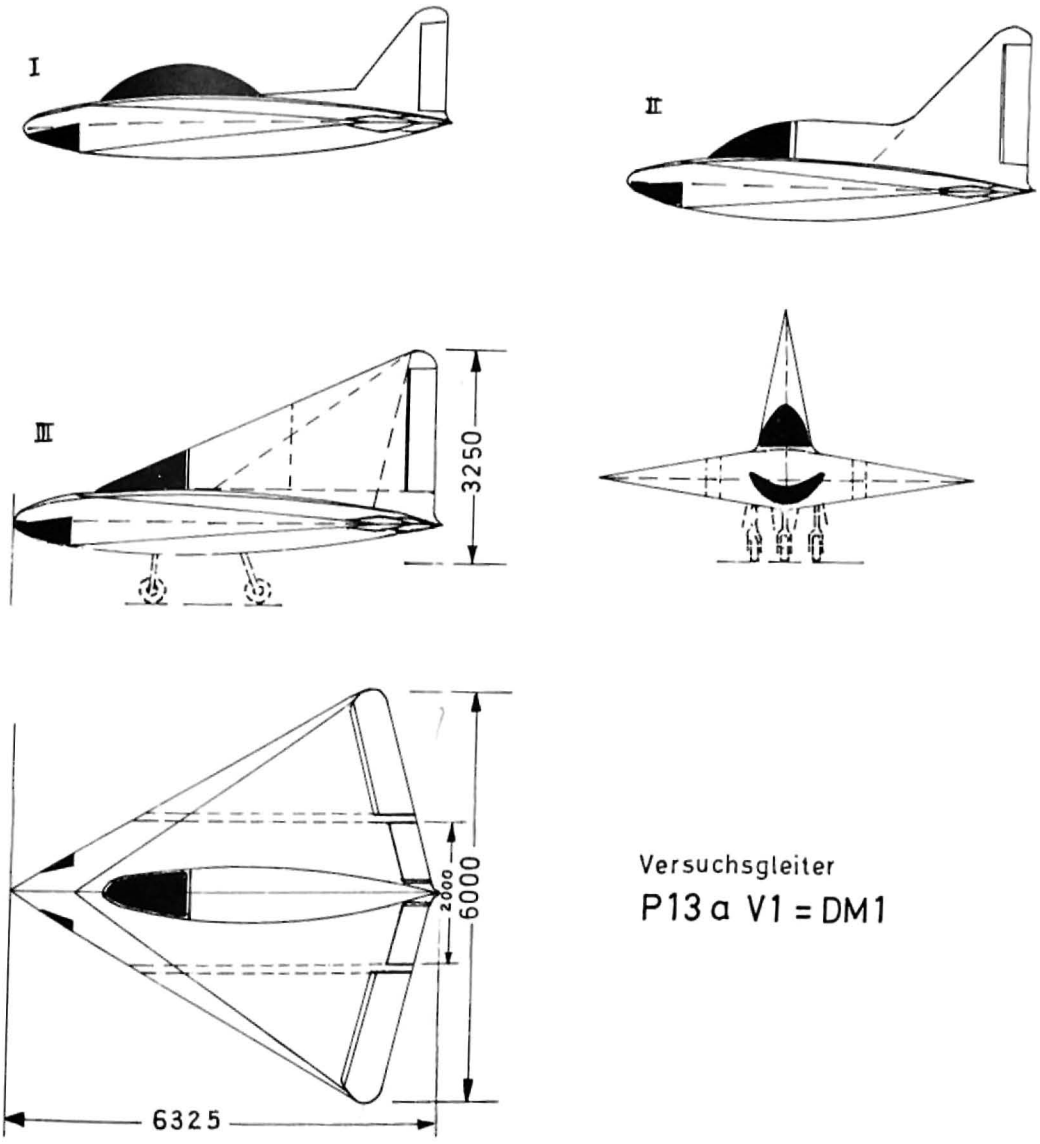


Fig. 86. Ramjet fighter project *P 13* of July 1944: (*Left*) layout; (*Right*) propulsion system; (*Below*) artist's conception of *P 13* in flight.

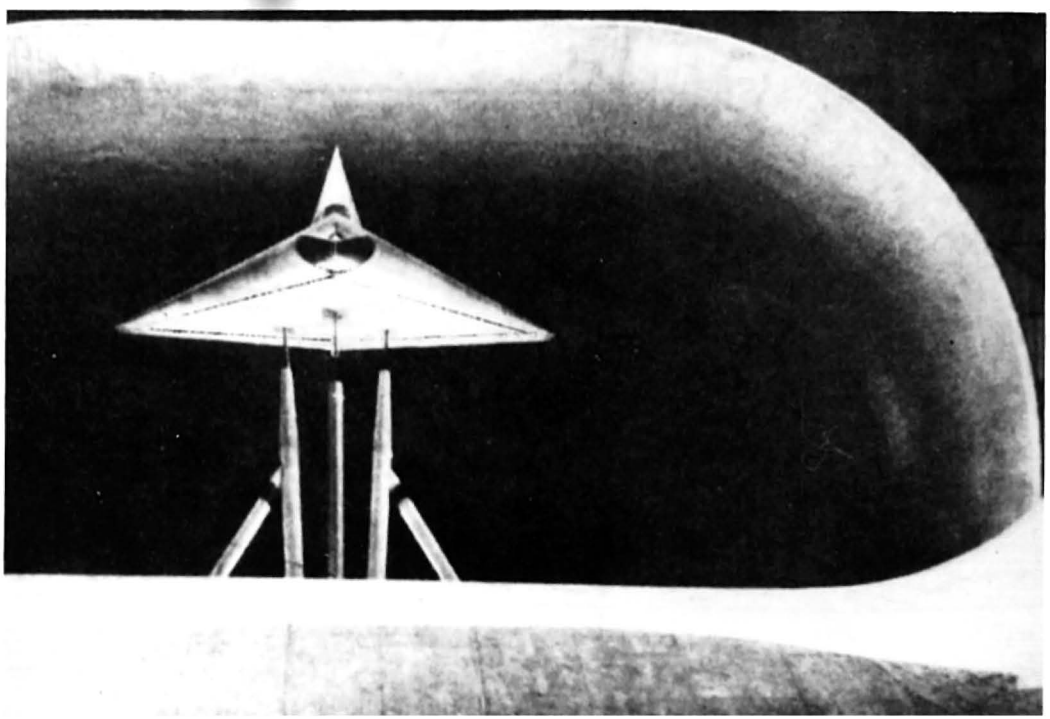




87a

Fig. 87a-c. Experimental glider *DM 1-P 13a V 1* (August 1944): (**a**) layout—version *I* and *II* were to be tested in flight before final version *III;* (**b**) *DM 1* in Prien after completion; (**c**) *DM 1* in the wind tunnel at Langley Field, Virginia (1946).

87b



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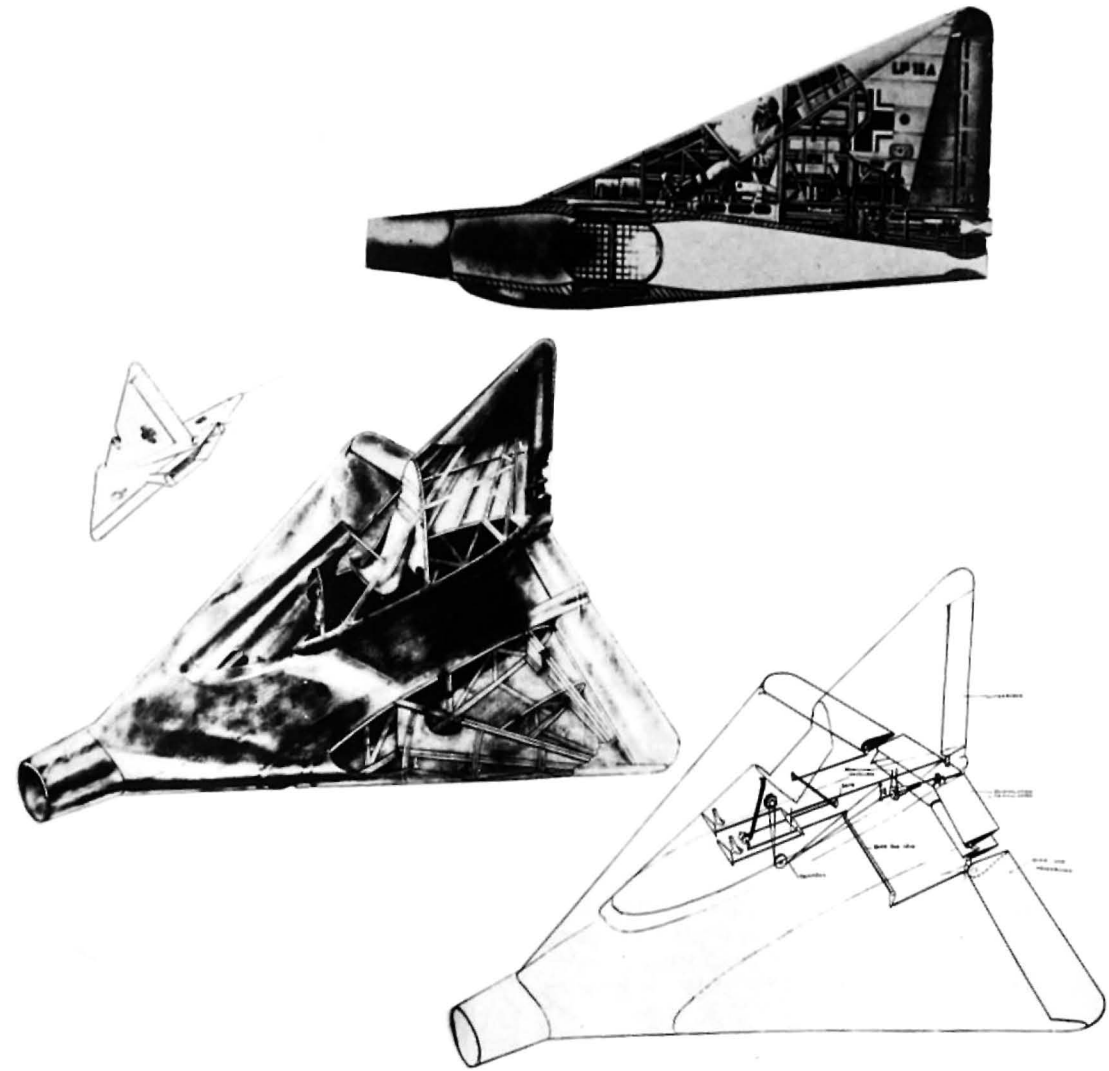
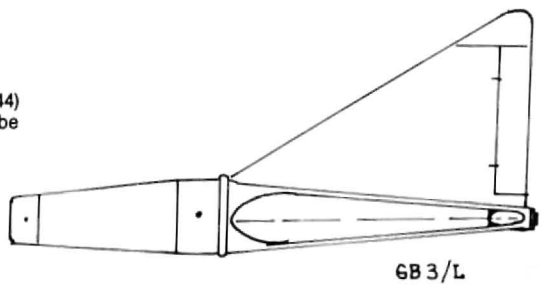


Fig. 88. Construction details of project *P 13a*.

Fig. 89. Project of the glide bomb *GB 3 L* (July 1944) with ramjet propulsion. Most of the structure was to be built of explosive material.



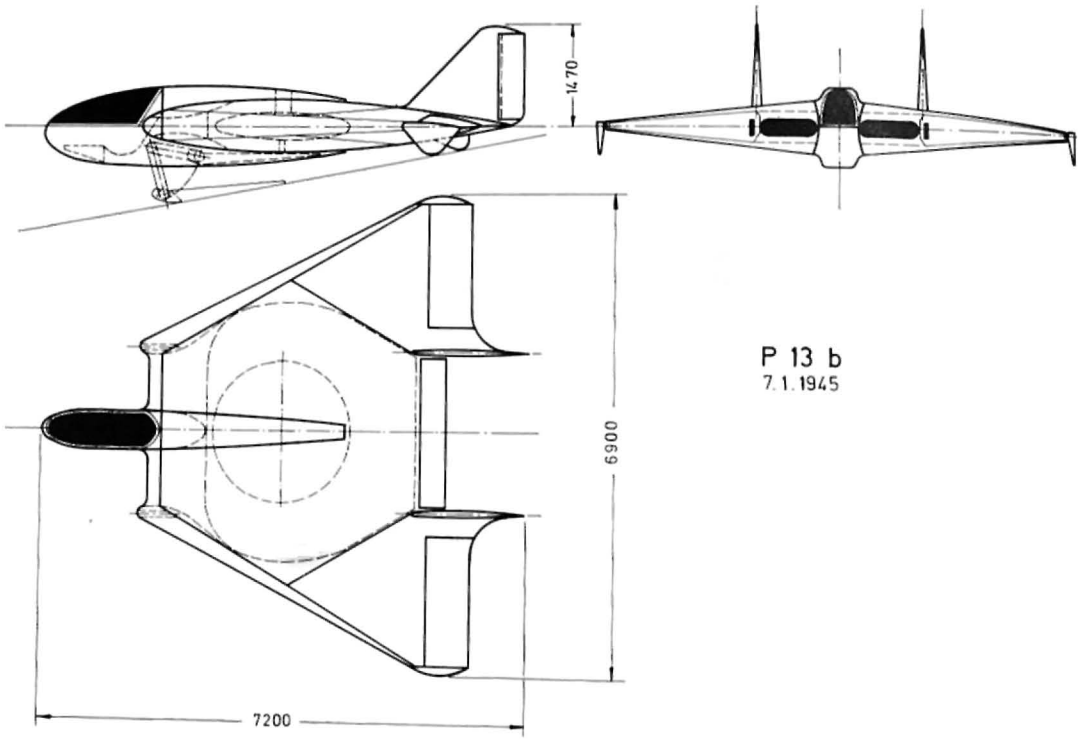
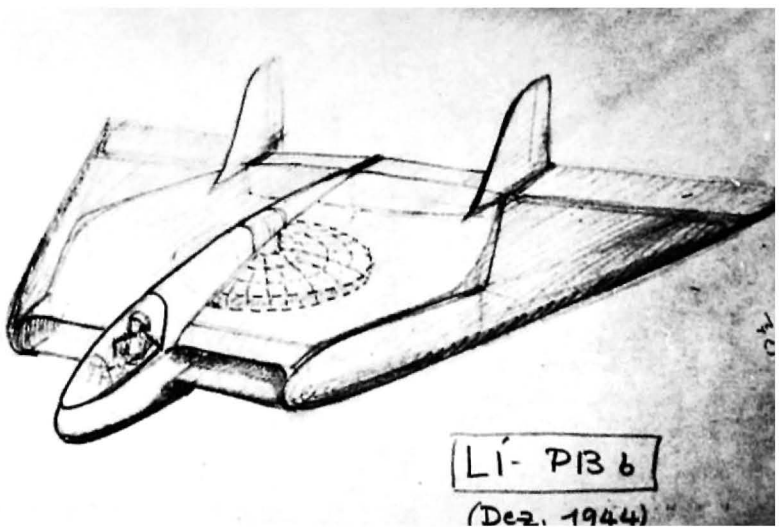


Fig. 90. Improved project *P 13b*, a ramjet fighter (December 1944).



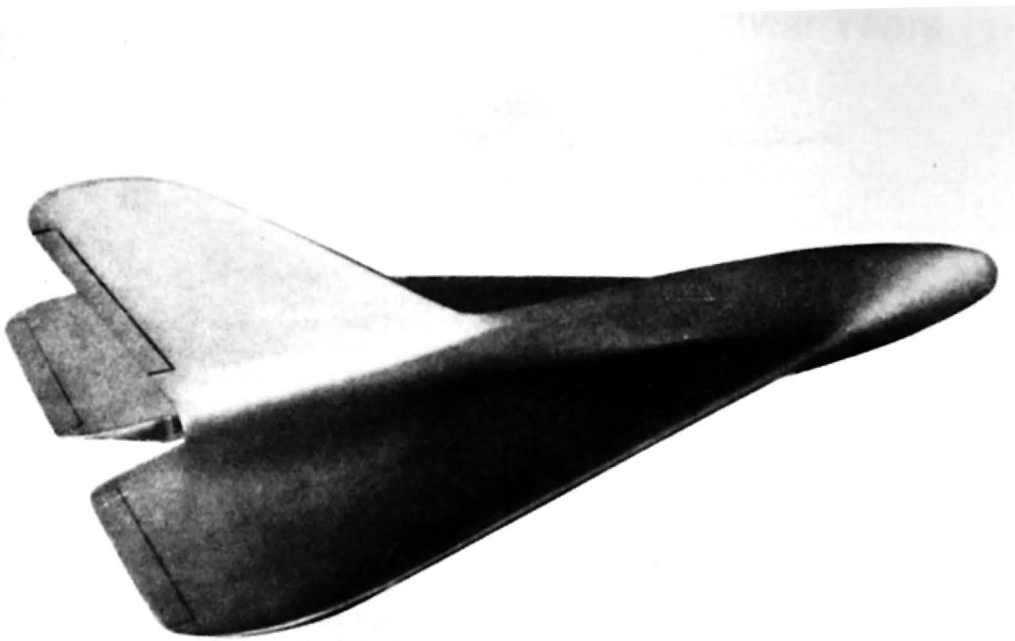


Fig. 91. Model of *P 14*, last project of a Delta aircraft with two turbines (spring 1945).

cussed a new project, the turbojet *P 15* (Fig. 92), which was to be assembled by using parts of other types of fighters and was expected to perform better than any of them. This plan was based on the fact that the rocket engines of the *Me 163* had in no way reached a satisfactory level of reliability, and that the "Volksjäger" (people's fighter) *He 162*—which had been created by "Blitzaktion" (lightning drive)—was not entirely satisfactory as far as range and flight characteristics were concerned. Project *Diana-P 15* was to be built using the wing of the *Me 163 C*, the cockpit of the *He 162*, and the modified fuselage (with nosewheel undercarriage and turbojet) of the *Ju 248*. This project did not progress beyond the first design drawings either.

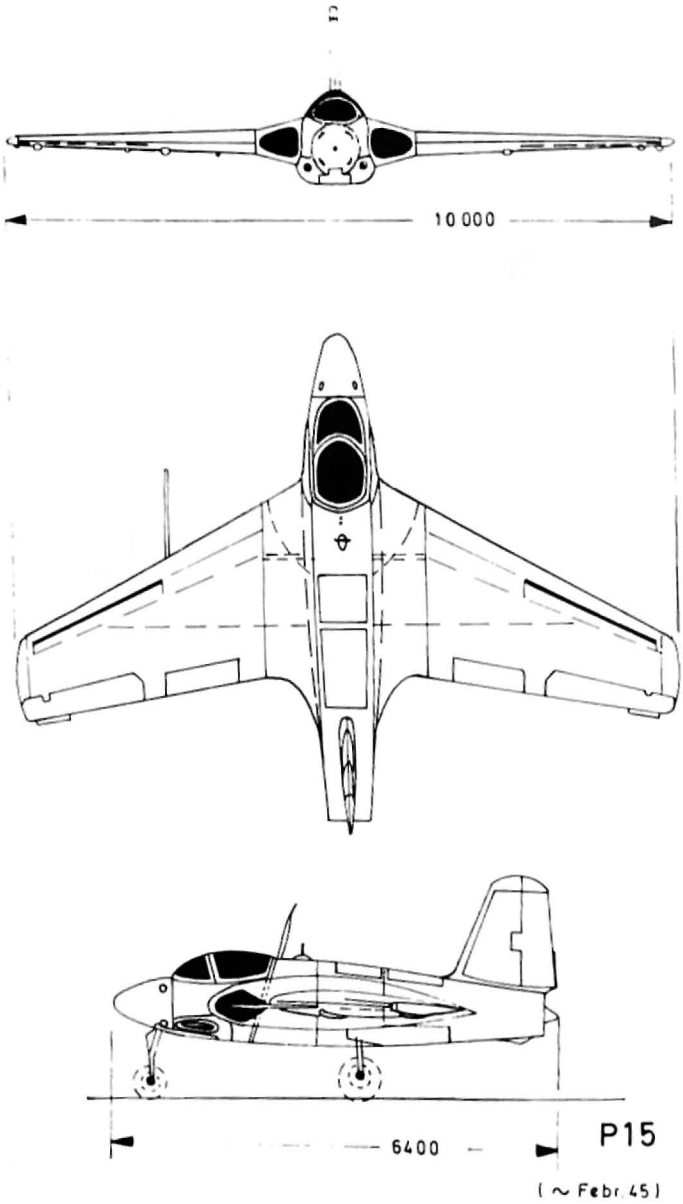


Fig. 92. Attempted reconstruction of the layout of the turbojet project *P 15* (February 1945).

7 Activities during the Early Postwar Years

AT THE END of the war we fled from Vienna before the advancing Russian army occupied the city, and we stayed temporarily in Strobl on the Wolfgangsee in western Austria. There I was contacted by officers of the Air Technical Intelligence of the U.S. Air Force. As early as May 23, 1945, an air force *DC-6* took me from Salzburg to Paris, where I was to give a report on my work on Delta aircraft before a panel of American aeronautical experts. When I had finished, one of the panelists gave me a friendly pat on the shoulder and said: "It looks very simple but too strange." In spite of this reaction, which was quite disappointing for me, I had succeeded in awakening the interest of my audience in this new type of design.

My transfer to the United States, which had been planned for the fall of 1945, was put off by protests in the United States against German scientists. With another group of German experts I was sent to England instead, where we were housed under military surveillance in a former school in Wimbledon. During the day, however, I was practically free, working in London on the evaluation of technical reports.

In January 1946 I was transferred to Wright Field, Dayton, Ohio, as a member of a group of German aeronautical scientists. Up to the end of 1946 we lived there in "protective custody" while our families stayed behind in Landshut, Germany, under American protection. In the beginning my activities were limited to the writing of reports. In collaboration with Dr. Friedrich Ringleb I wrote a paper on the theory and design of ramjet engines, which was printed by the U.S. Navy. In the course of the year 1946 I also had the opportunity to go on an extended lecture tour to California with Lieutenant Robiczek. The engineers of Convair followed up on some of my suggestions and started the design and construction of Delta aircraft.

In December 1946 our presence in the United States, which had hitherto been kept secret, was made public. From that time on we were able to move freely and in May 1947 my family joined me in this country.

In the meantime the completed *DM 1-P 13a V 1* had been transported to the United States. It was tested in the full-scale wind tunnel of the Langley Field Aeronautical Laboratory (Fig. 87c). The results of the measurements were published by the National Advisory Committee for Aeronautics (NACA), and a further report—in which my name was not mentioned however—contains the proposal to start the planned flight testing by replacing the large rudder, which was constructed as an extension of the cockpit, with a separate canopy and a smaller rudder (Fig. 87a).

In the course of the wind tunnel tests a number of highly interesting phenomena appeared, which were caused by the Reynold's Effect. In order to acquaint themselves with the characteristics of this unusual design, the NACA aerodynamicists built a model in reduced scale, which was tested in the small wind tunnel. When the full-size airplane was measured in the full-scale wind tunnel the measurements showed that the lift coefficient of the large airplane amounted to only 50 percent of that of the small model. This loss was attributed to premature stalling, and attempts were made to remedy this loss by giving the leading edge of the wing tips a more pointed shape. But only after the sharp edges were applied to the

midwing section directly at the leading edge were the original values of maximum lift and a linear function of the moments regained.

At Wright Field I was asked to participate in a meeting with the representatives of the NACA where I was requested to further study this specific phenomenon. I was able to shed some light on this problem and presented my findings in a concise report. Owing to the Reynold's Effect the flow around a body is either subcritical or supercritical. This effect has been studied by measuring the flow around spheres in the wind tunnel at different Re numbers. An NACA technical memorandum was also published on this effect. It is possible that similar discrepancies which appeared in tests during the development of the *Aerofoil Boat X-113* were caused by related effects.

I also made some small contributions on the problem of seat ejection trajectories while working at the Naval Air Material Center in Philadelphia, Pennsylvania.

When in 1949 the U.S. military budget was reduced, employment of the German scientists by government agencies became difficult and we were permitted to search for employment in private industry. In 1950 I joined the Collins Radio Company in Cedar Rapids, Iowa, as an expert on special aeronautical problems, which demanded a thorough knowledge of aerodynamic sources.

8 Work at the Collins Radio Company and in Connection with the Lippisch Research Corporation

WHEN I started work at the Collins Radio Company on February 2, 1950, my first project was a radio-controlled drone, i.e., a small, unmanned remote-controlled aircraft that would be capable of attacking and destroying enemy bombers. For this purpose I suggested a "High Speed Delta" design and we proceeded to test a series of Delta wings with low aspect ratio. We started by flying a small model (Fig. 94) and subsequently built three larger models (Fig. 95) with V-shaped nose controls powered by a 2.5 h.p. Dooling engine with a shrouded propeller. The remote-control system for the model was developed by Collins. The model, which weighed 24 kg, performed two good flights but was later destroyed in a crash landing. For reasons not under my control the project was later discontinued.

This work had been supported by the Office of Naval Research, Air Branch, in Washington, D.C. This office was especially interested in a smoke tunnel for flow visualization at higher speeds and we therefore built a two-dimensional smoke tunnel for the Aerodynamics Institute at Princeton University which proved very satisfactory.

In previous years I had repeatedly tried to

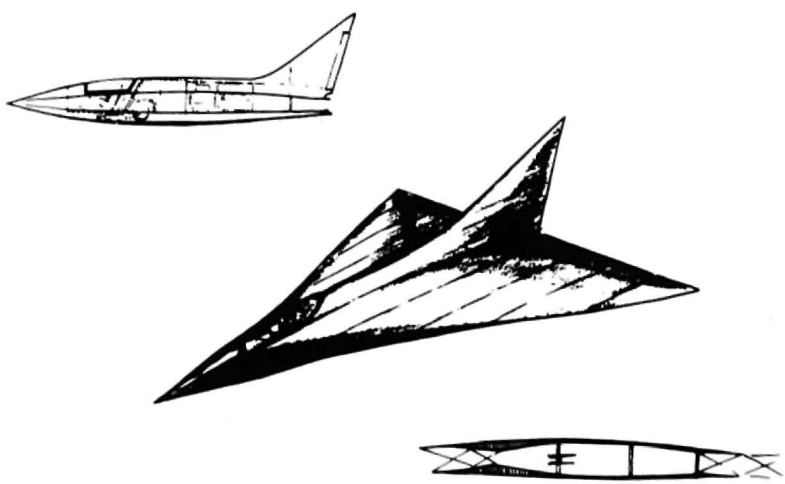


Fig. 93. Design of a supersonic ramjet airplane (from a lecture given in USA).

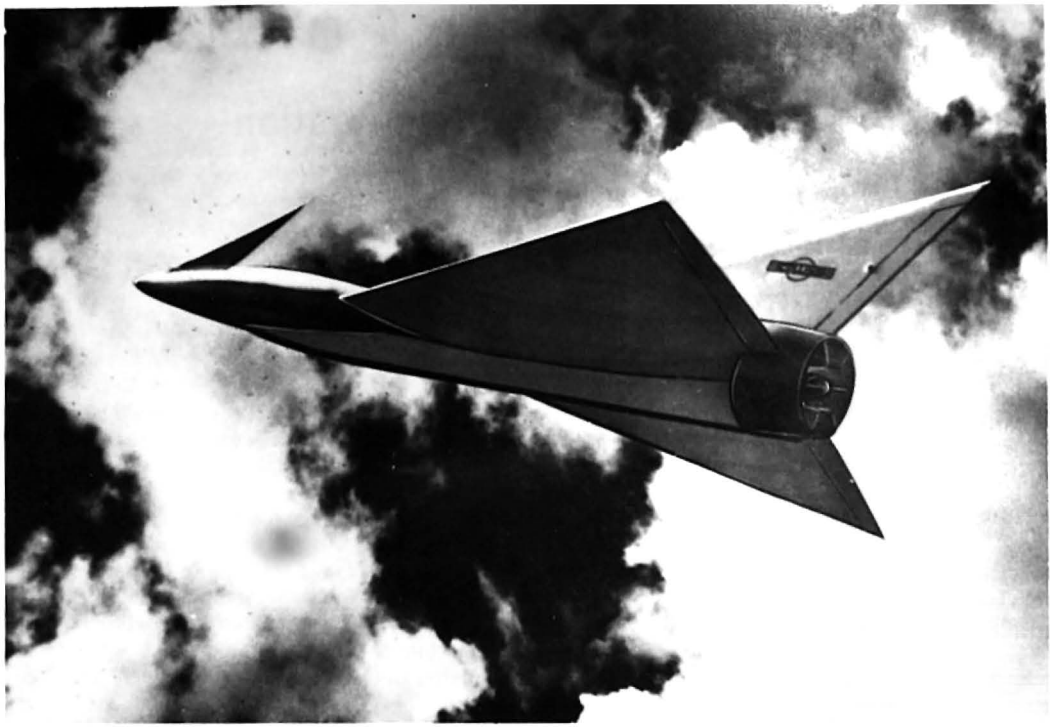


Fig. 94. Free-flight model of a drone with Delta wing built at Collins Radio Company.

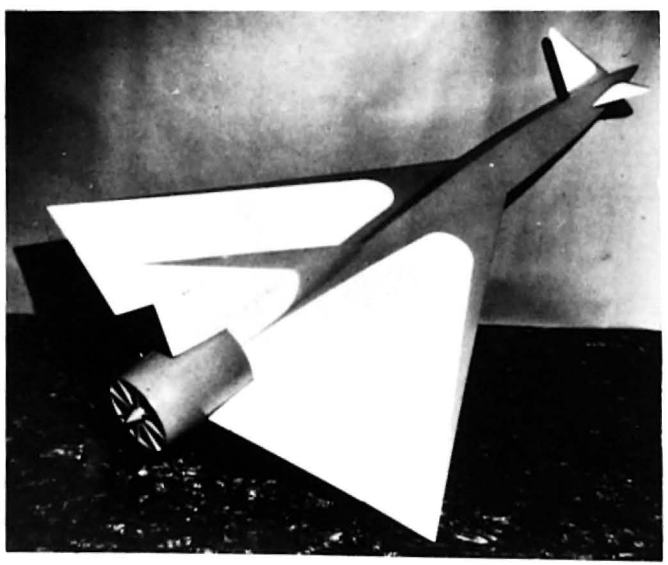


Fig. 95. Large model of an interceptor drone of the Collins Radio Company (wingspan 2.83 m).

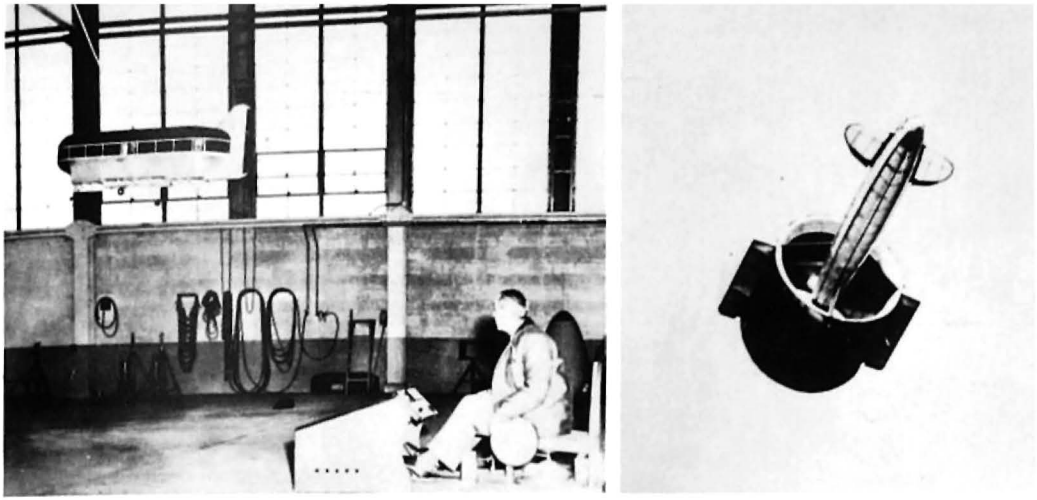


Fig. 96. Two hovering devices which were tested at Collins Radio Company (1951–53).

solve the problem of combining the production of lift and thrust in one process, instead of creating *thrust* by means of horizontal propeller propulsion and *lift* by circulation of the airflow around the wing as is the case in traditional aircraft. Thus I turned to the opposite extreme of all-wing design, namely wingless aircraft.

After testing a number of different arrangements, I finally decided to perform some simple preparatory tests with shrouded propellers. The first test with a vertically rising shrouded propeller revealed that the true problem in stationary hovering flight lies in providing flight stability, for in this case no stabilizing forces are to be expected from the outer stationary air. Only by installing gyros which were restricted in one axis, was it possible to create the damping forces on the jet controls which guarantee a stable hovering flight.

In 1951 we built and tested several simple hovering models (Fig. 96) which were driven by electromotors powered via cables. In 1953 these hovering devices were presented to the navy in the large National Armory Hall in Washington, D.C. Later (after my retirement from Collins) I continued the development of these flying bodies which have become known as Aerodynes (Fig. 97). In 1967 the Dornier Aircraft Company in the Federal Republic of Germany took over the development of the Aerodyne with myself acting as consultant and obtained remarkable results with a large, unmanned, electronically controlled model.

In 1960 Arthur A. Collins appointed me head of the Hydrodynamics Laboratory of Collins Radio Company, which was to develop a boat designed for special purposes. My main assistant was Russell Colton. We built a tow tank of 30 m length which led to a number of highly interesting test results. We came to the conclusion that, due to problems of density and cavitation, boats moving at velocities above 50 km/h should if possible be raised outside the water onto an air cushion. However, this solution, which was successfully used by Cockerell in his Hovercraft vehicles, appears inefficient for long-distance travel. Based on my study of the NASA test results of the ramwing of T. J. Kaario (patented as early as 1935), a 1921 publication by Wieselsberger on the theory of ground effect on aircraft, and on tests of my own I decided to explore the aerodynamic ground effect both in theory and practice.

We started by designing and building a semi-

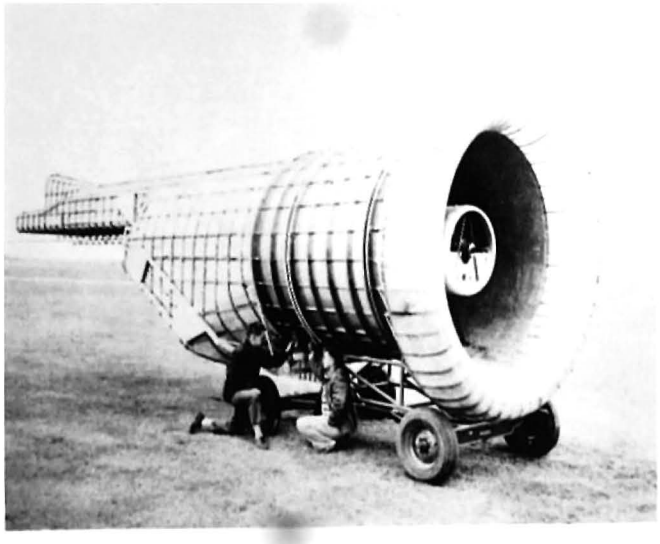
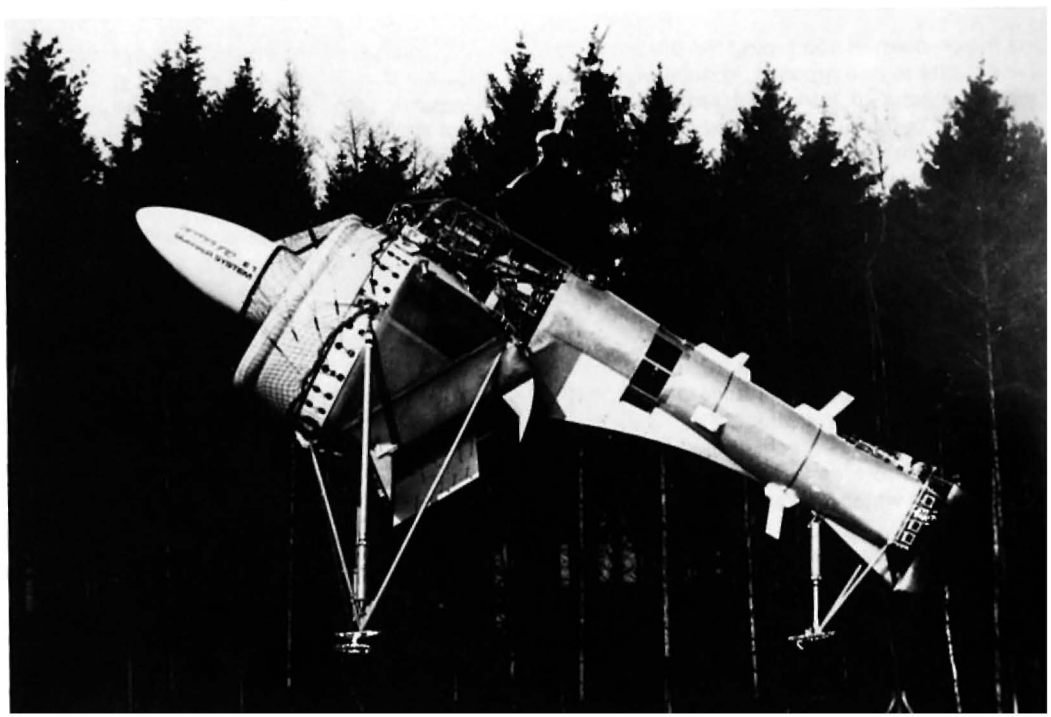


Fig. 97. Original design (mock-up at Collins, 1957) and later shape (Dornier, 1974) of the Aerodyne.



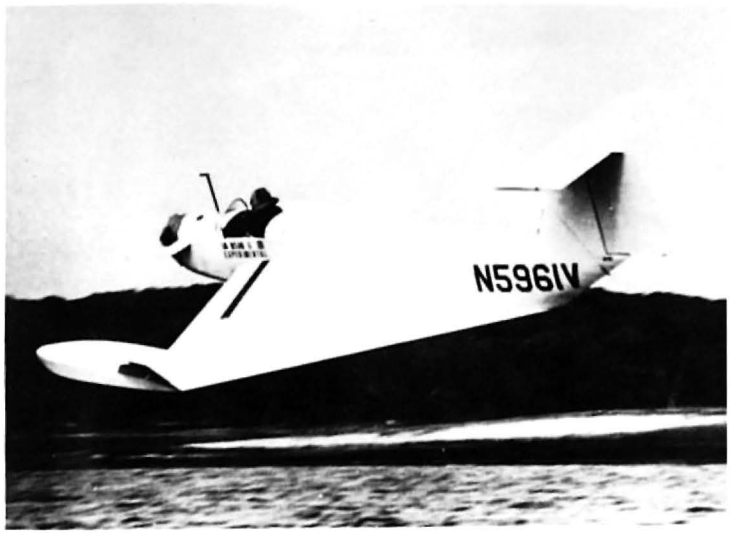


Fig. 98. Ramwing vehicle *X-112* (Collins, 1963).

elliptical model of a ramwing for tests in our small tow tank at the Collins Radio Company. Although the velocities used in these measurements were relatively low compared to wind tunnel tests, the test results showed favorable characteristics, which indicated that on wings of low aspect ratio, higher glide ratios (lift/drag) could be obtained due to the influence of ground effect. In the Collins Hydrodynamic Laboratory we built a simple two-man ramwing craft, the *X-112* (Fig. 98) which was successfully flight-tested in the fall of 1963 by pilot Clayton Lander. Such an Aerofoil Boat has a very simple structure which—although it looks somewhat like an inverted Delta—is not related to the Delta wing, since it was developed from a simplified half of a streamlined body [81-84].

In 1966 I founded my own consulting firm, Lippisch Research Corporation, and developed the *X-113 A Aerofoil Boat* (Fig. 99) which was built at the Rhein-Flugzeugbau Company in Mönchengladbach in the Federal Republic of Germany. It was successfully test-flown on the Lake of Constance and the North Sea. A larger version of the Aerofoil Boat is presently being built by the same company.

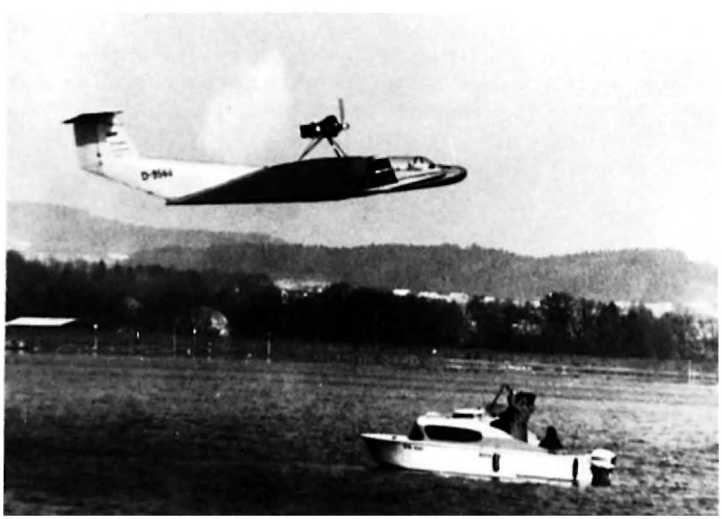


Fig. 99a,b. *Aerofoil Boat X-113 A* (Rhein-Flugzeugbau Company).

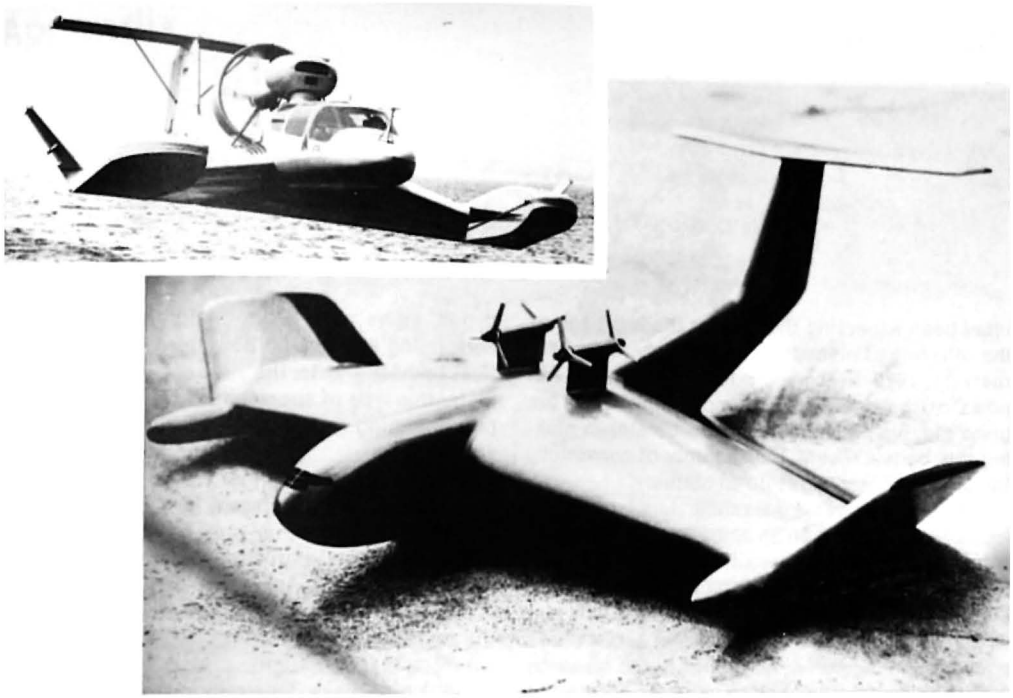


Fig. 99c,d. Demonstration models of a two-place and a large version of the *Aerofoil Boat*.

Fig. 99e. Flight-testing the *Aerofoil Boat X-114* of Rhein-Flugzeugbau Company (1977).

Postscript

I had been expecting the text for the last page of the otherwise finished manuscript when, on February 11, 1976, I received a telegram bearing the news of the death of Alexander Lippisch. This gives me, his colleague and collaborator in making this book a reality, the sad duty of converting the unwritten last page into an obituary.

In his later years Alexander Lippisch could look back neither upon an aircraft company of his own nor a great number of aircraft bearing his name as did his contemporaries Ernst Heinkel and Hugo Junkers, to name just these two pioneers of aeronautics. His life was not dedicated to conventional aircraft construction but to research and the uncompromising pursuit of new solutions. As this book documents, he proved the feasibility and worth of tailless and all-wing aircraft in spite of seemingly insurmountable obstacles and many setbacks. Just "on the side" he created a respectable series of training gliders and soaring planes of "normal" layout, which at the time of their appearance served as models for all competing designs worldwide.

By his development of the Delta wing Alexander Lippisch paved the way for supersonic flight. The wing design which is used today on supersonic aircraft is proof that the solutions which Alexander Lippisch proposed in the 1940s and defended against the opinions of many experts were right, and that he was far ahead of his time.

After World War II Alexander Lippisch was especially fascinated by the extreme opposite of the all-wing airplane—wingless aircraft. With automatic stabilization, wingless aircraft—Aerodynes, as he named his design—are capable of performing at all velocities, from hovering to vertical takeoff and to the highest forward speeds. So far this type of aircraft has only flown without a pilot, opening new horizons for unmanned flying vehicles.

At an age when most men are happy to go into well-earned retirement, he started the development of still another type of aircraft, the ramwing or Aerofoil Boat. Compared to other ground effect vehicles (e.g., the Hovercraft), the Aerofoil Boat has markedly greater hovering distance from the surface and much higher efficiency, especially in long-distance flight.

Each of these developments would have sufficed to assure him a place among the leading men of technical progress. It should be emphasized that he gave the world not only new ideas but also prototypes ready for production.

In spite of his achievements he always remained unassuming, barely mentioning difficulties he had overcome, and he never lost his sense of what could actually be realized within the limits of efficiency.

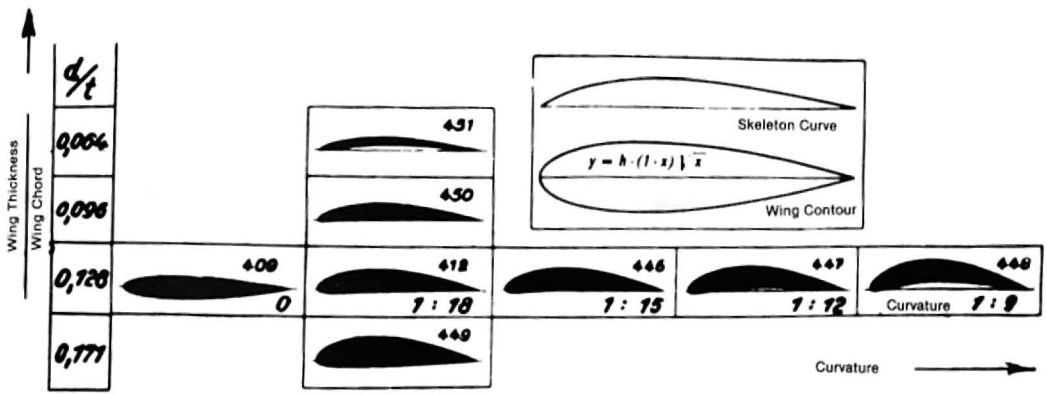
However, he was adamant in protesting false or inaccurate representation. This fact indeed led to the purely technical documentary reporting of this book, which ignores his ability to present human events in an informal and humorous style.

Fritz Trenkle

Fürstenfeldbruck
West Germany

Appendix

1) Systematic Profile Measurements 1918



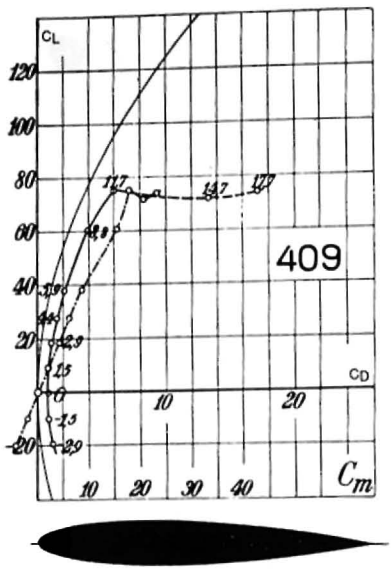
These measurements were published in "Ergebnisse der Aerodynamischen Versuchsanstalt Göttingen, 1. Lieferung" (Results of the Aerodynamic Research Institute, Göttingen, vol. 1)

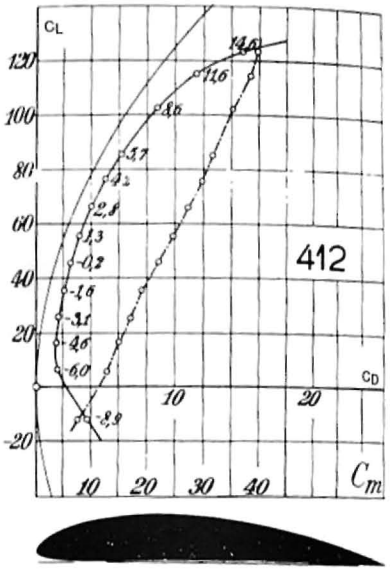
They show the effect of wing thickness and curvature on the lift coefficient C_L, the drag coefficient C_D, and the pitch moment coefficient C_m. In this graph C_L, C_D, and C_m have been multiplied by 100.

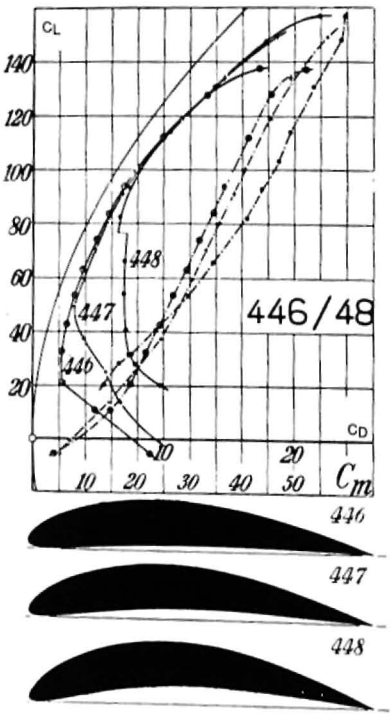
C_L Lift Coefficient

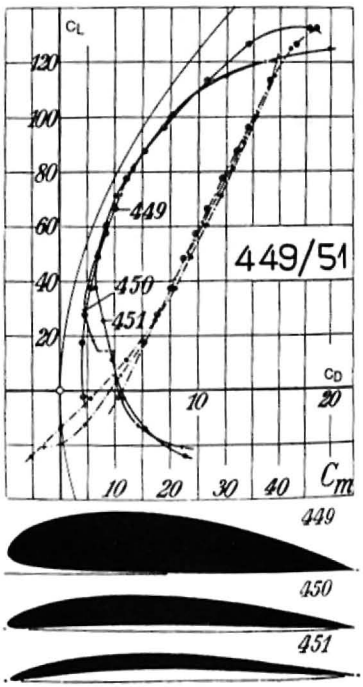
C_D Drag Coefficient

C_m Pitch Moment Coefficient

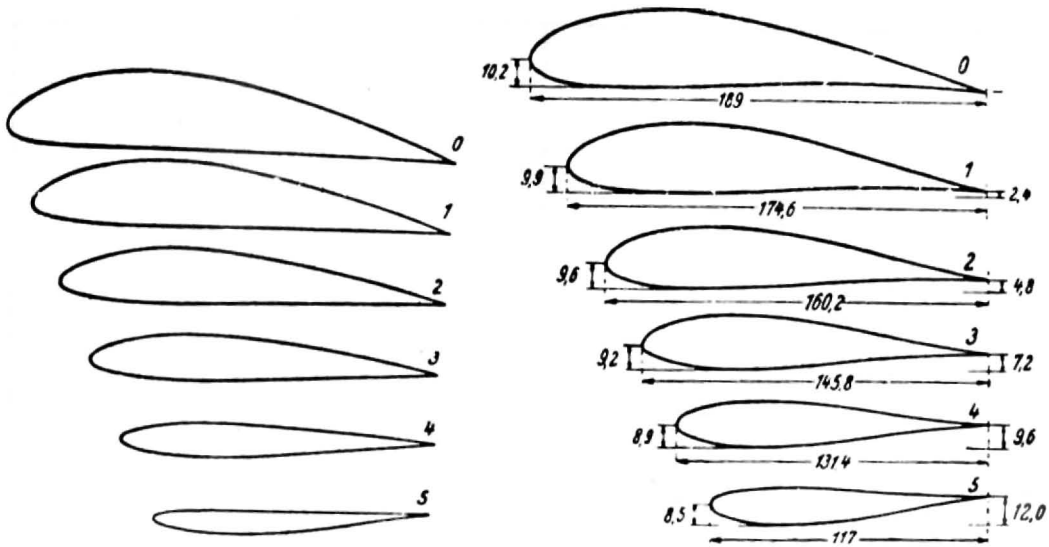


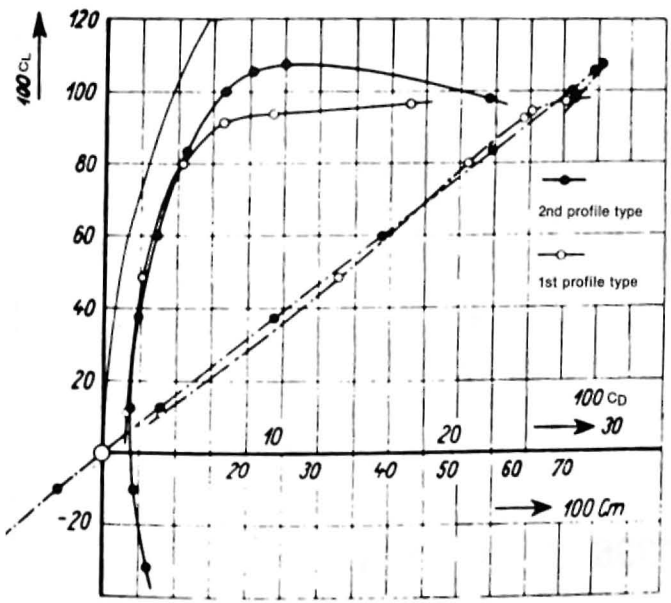




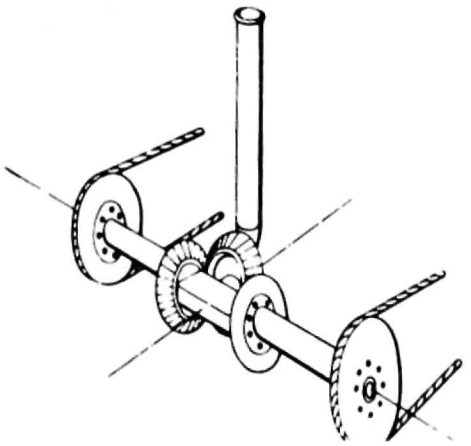


2) Wind Tunnel Measurements for *Stork I*

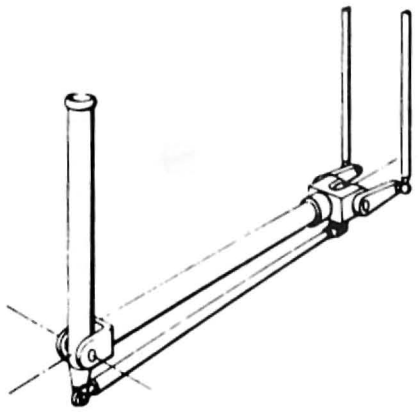




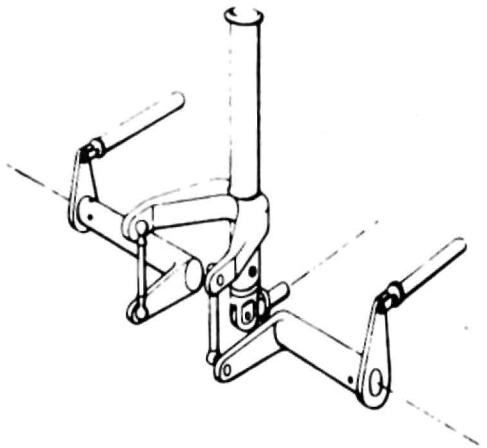
Wing Sections and Test Results on a Wind Tunnel Model of *Stork I*.



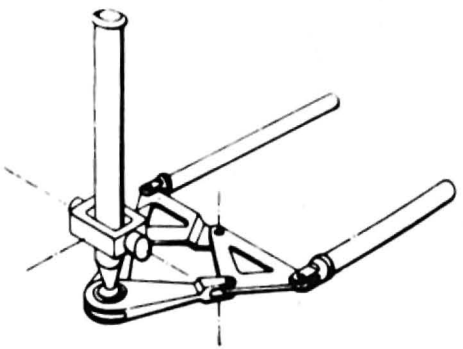
Stork IX 1933



DFS 194 1937

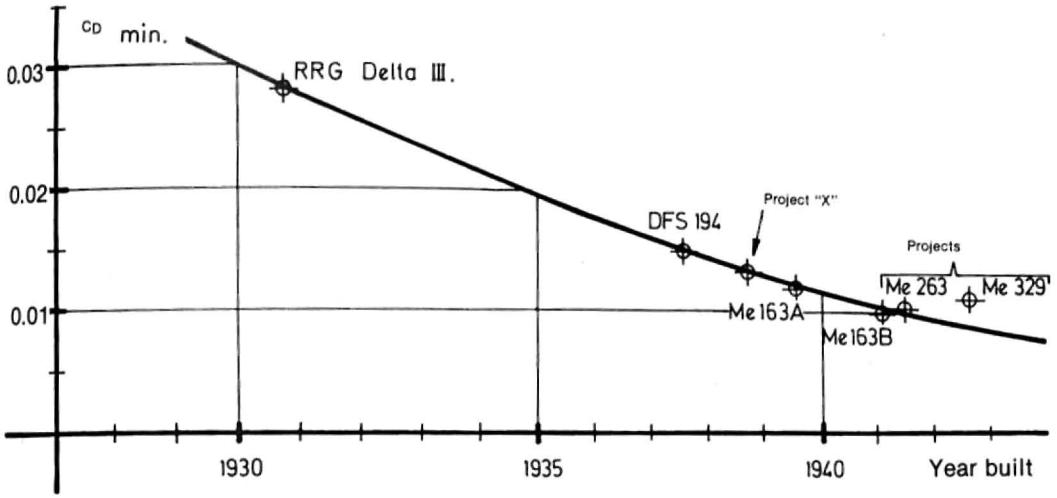


DFS 39 (Delta IV) 1936

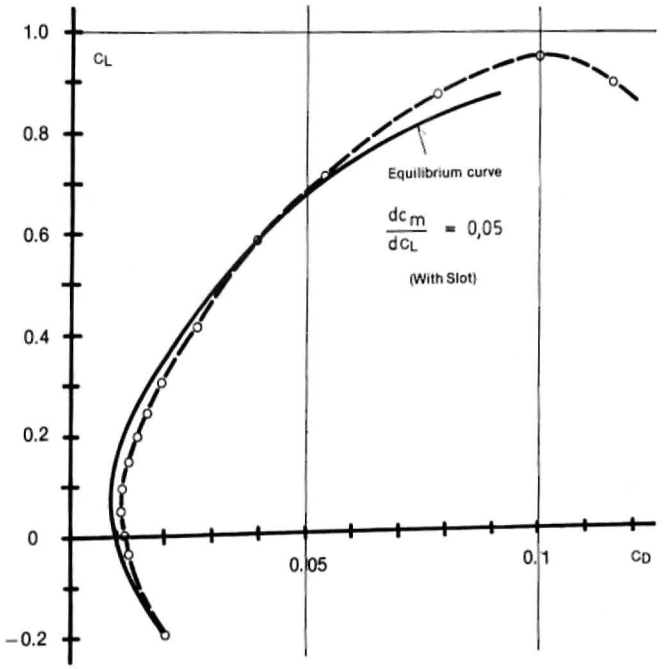


Me 163 1940

4) Aerodynamic Improvement of Delta Aircraft

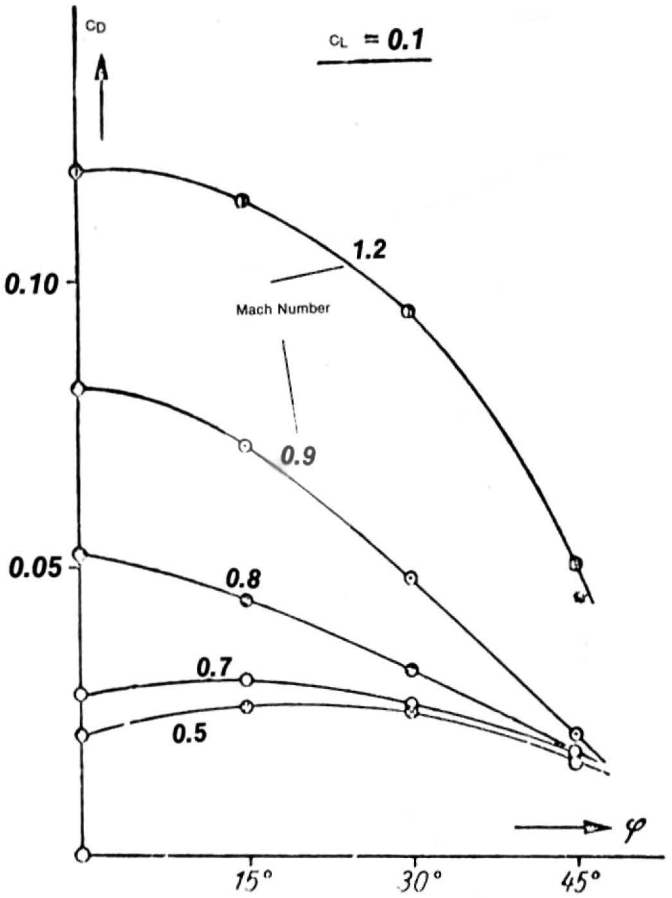


This graph shows the constant decrease of the minimum drag coefficient in the course of the development of tailless aircraft.



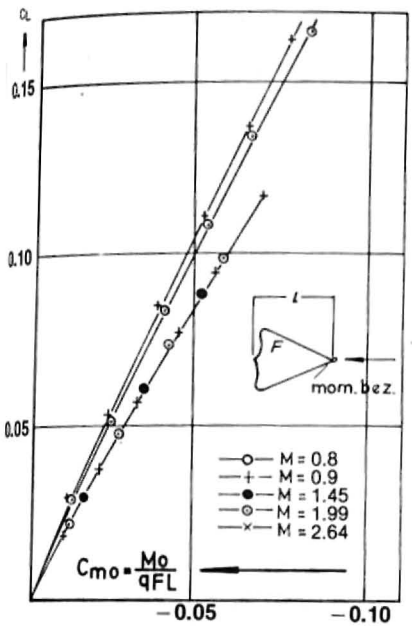
Polar curves of *Me 163 B*. It shows that deflection of control flaps in high speed flight even produces a reduction of drag.

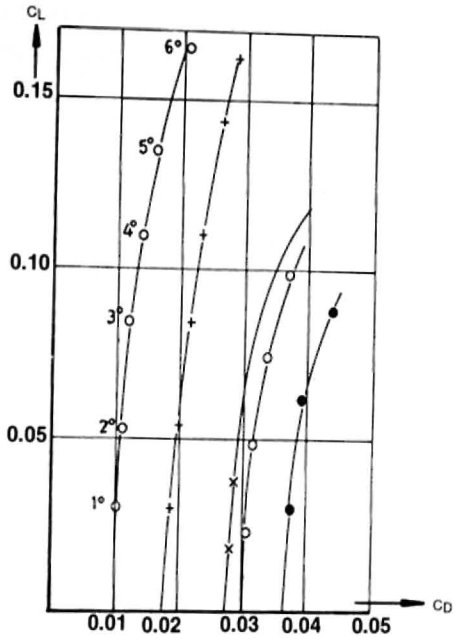
5) Results of Measurements on Swept Wings

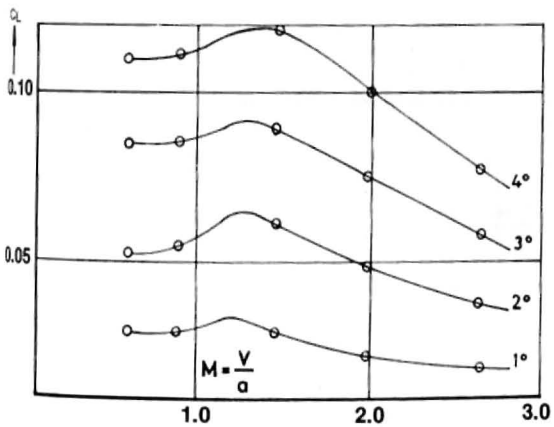


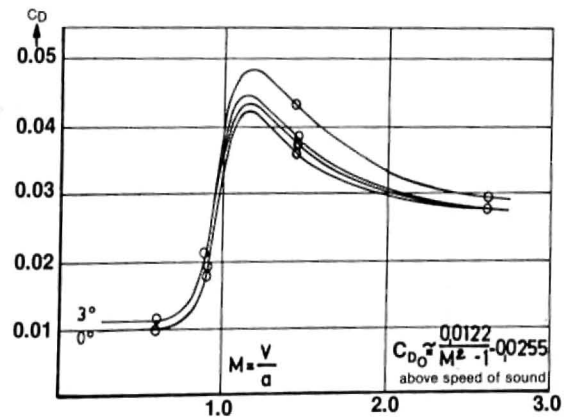
Test results at the Aerodynamischen Versuchsanstalt Göttingen on wings with different angles of sweepback in relation to the Mach number (1943). C_D — Drag Coefficient, φ — Angle of Sweepback.

6) Test Results on a Supersonic Delta Model



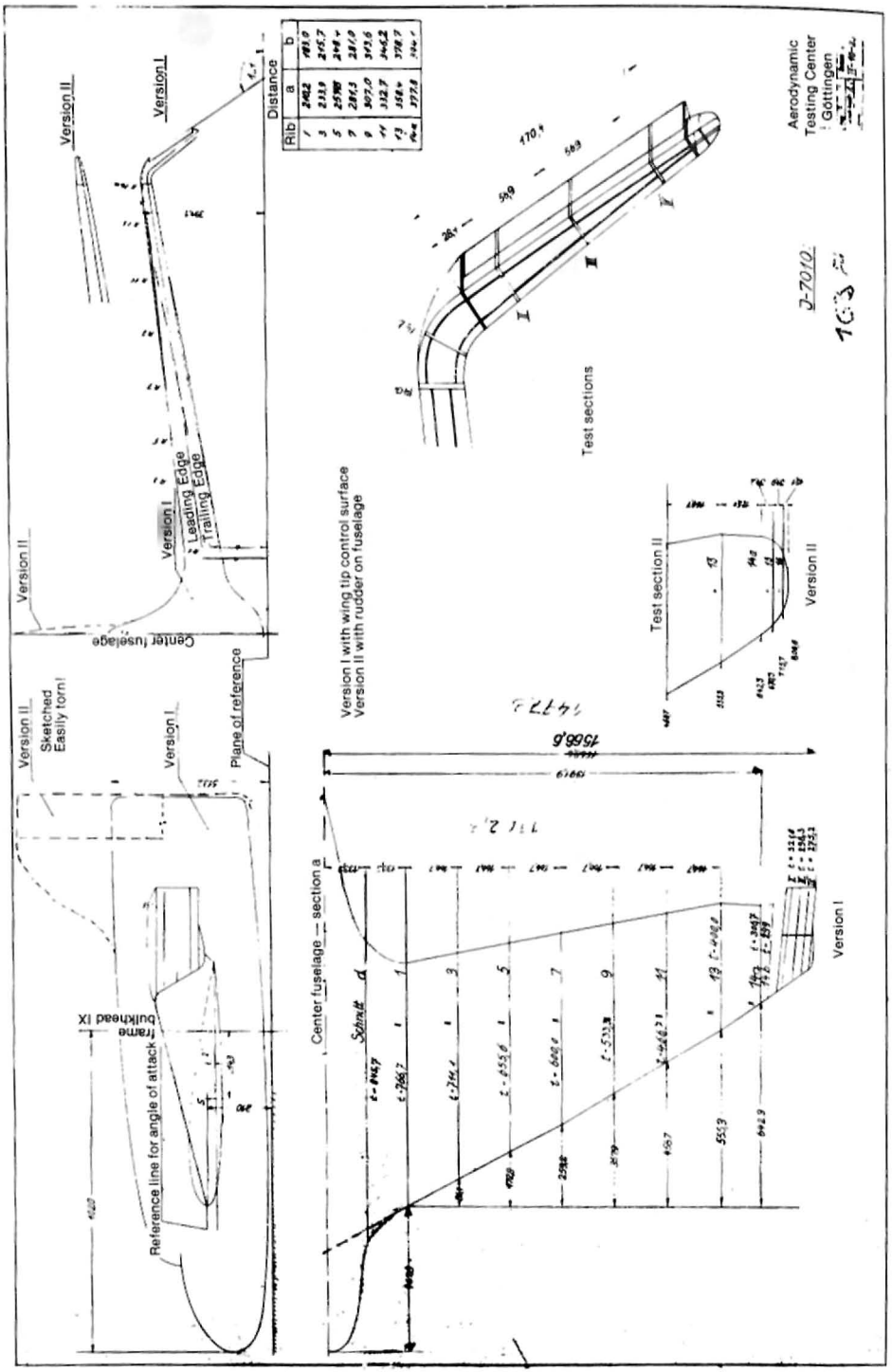


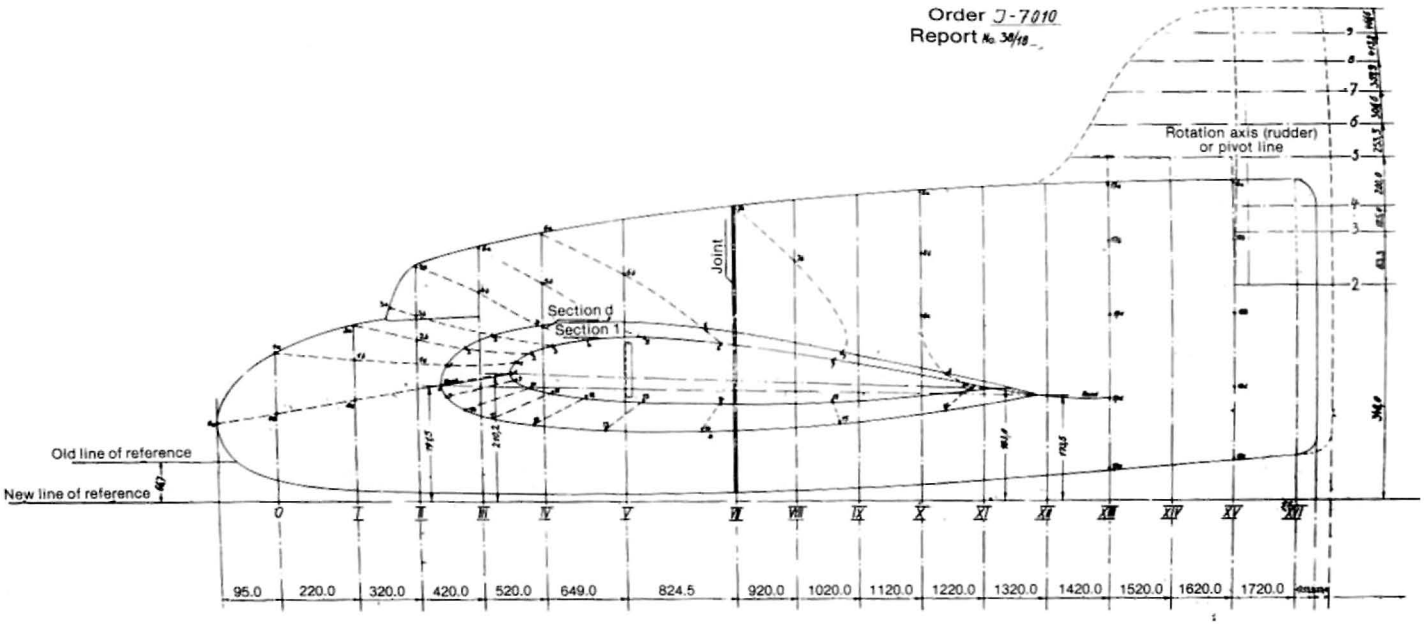


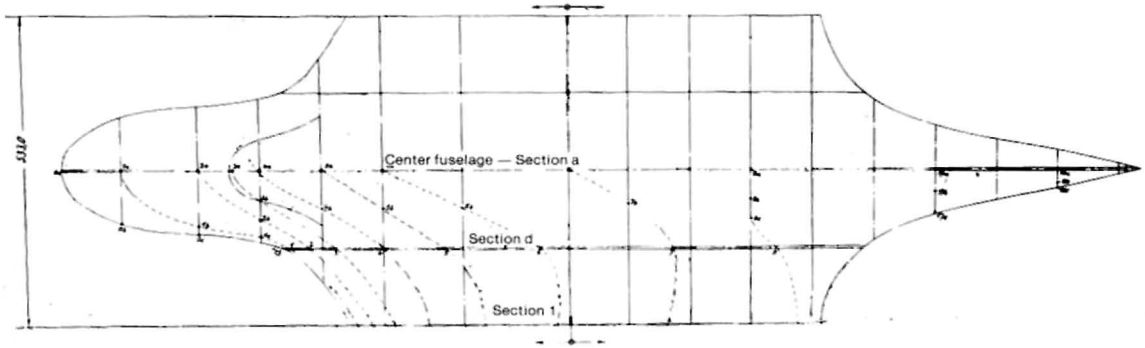


Test results on a Delta wing model with high angle of sweepback (see Fig. 82). A very similar type of wing is used on many of today's supersonic aircraft. This model was designed in 1942.

7) Wind Tunnel Model Drawings for *Delta IV d/Project X* (1938)





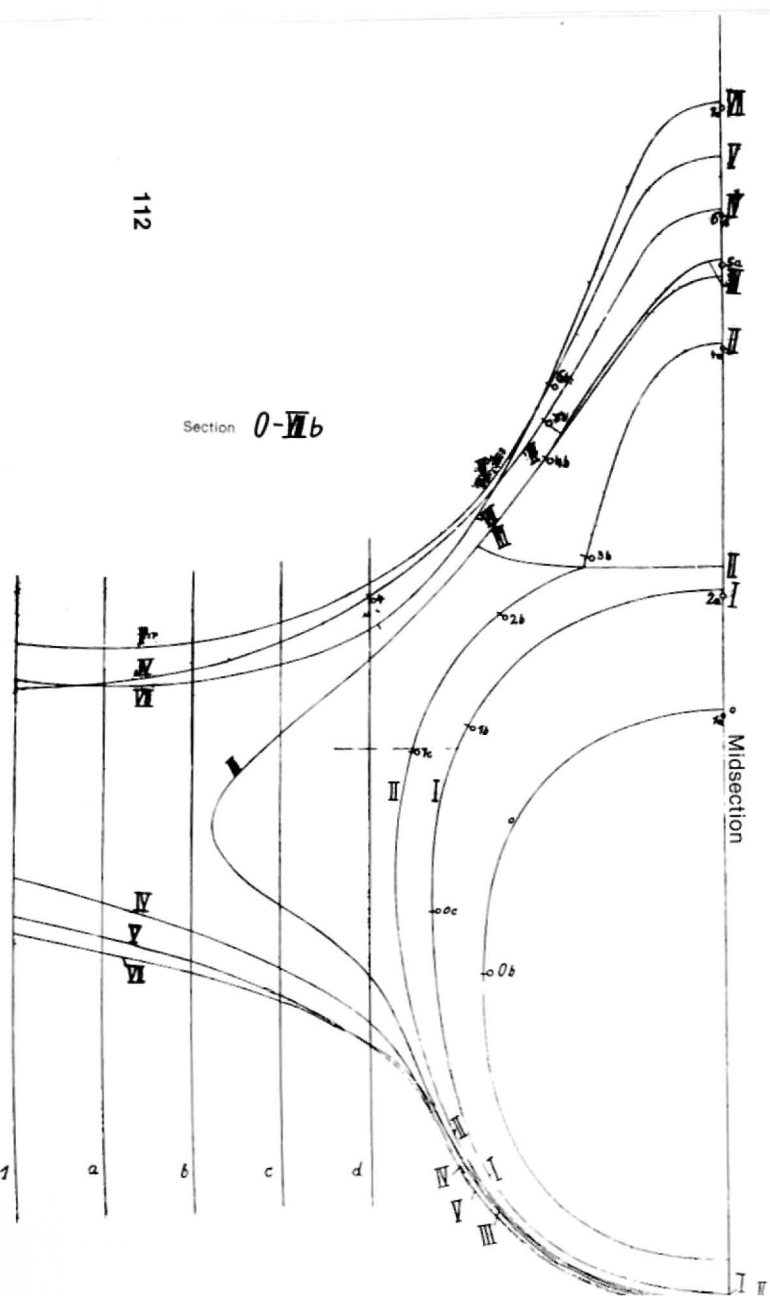


Test points on fuselage
Version I with wing tip rudder
Version II with rudder in fuselage
(Siehe gezeichnete Konturen)

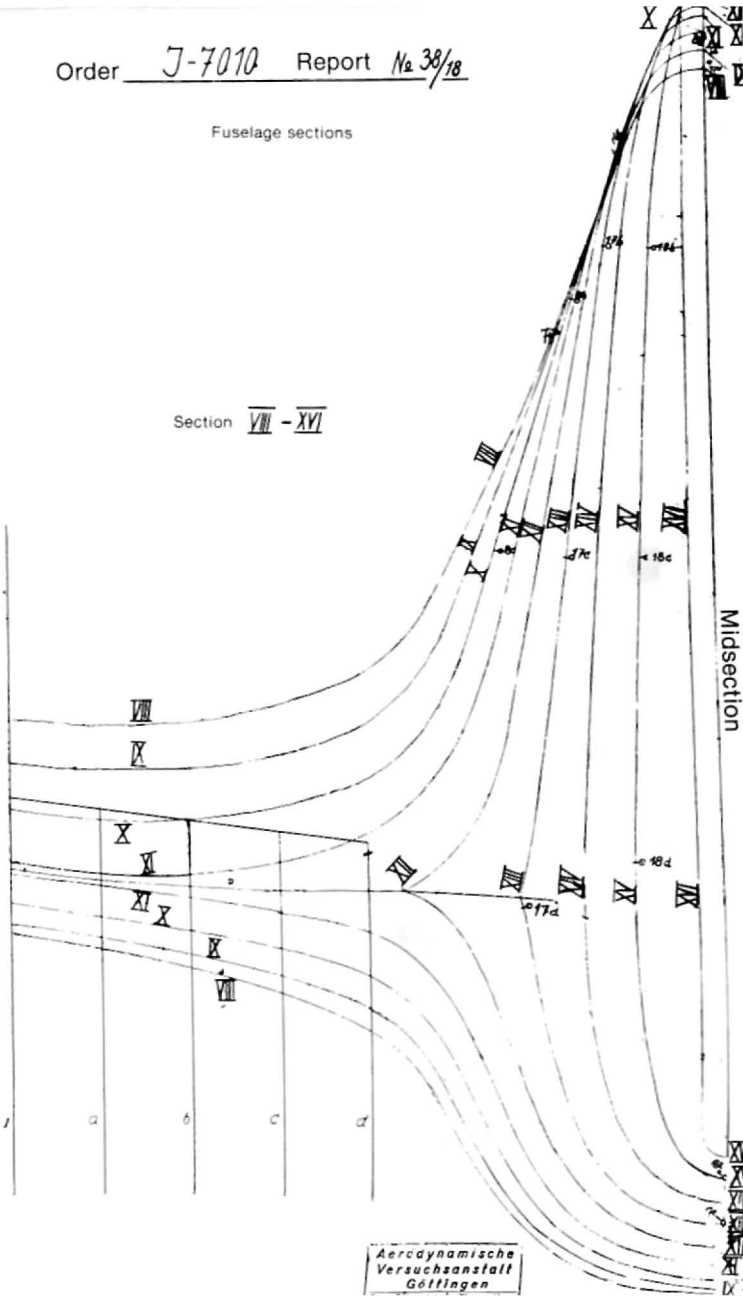
Order J-7010 Report № 38/18

Fuselage sections

Section 0-VIb

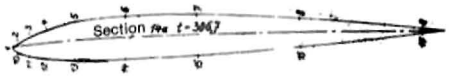


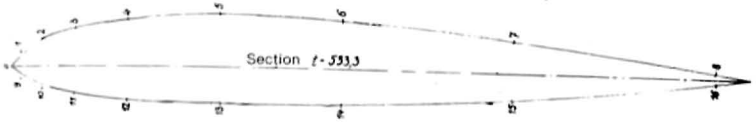
Section VIII - XVI



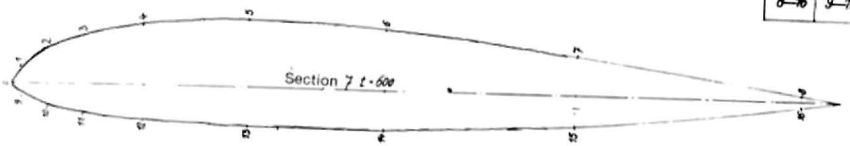
Aerodynamische Versuchsanstalt Göttingen

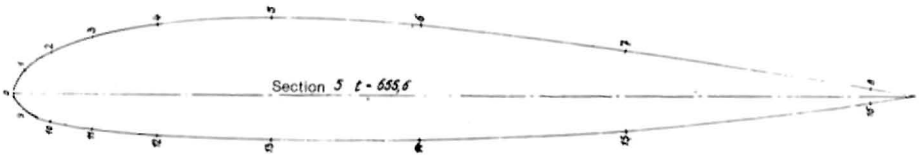
Order J-7010
Report No. 38/18

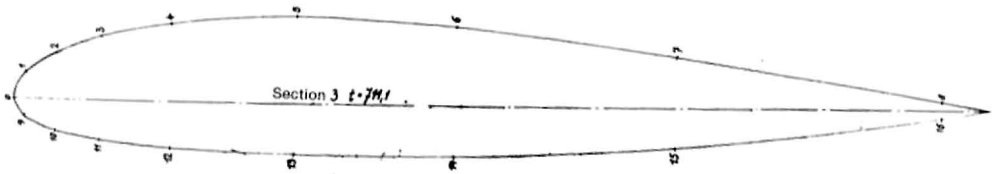


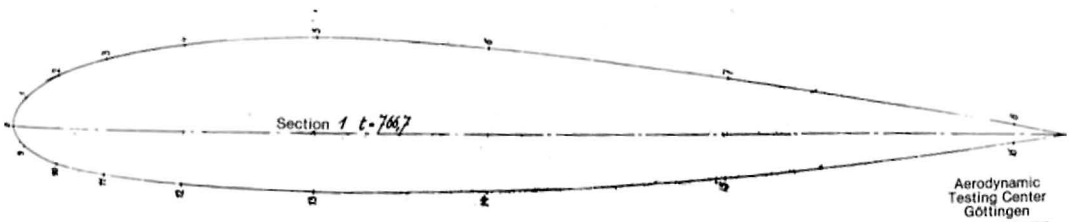


Section 1—13	Section 14a	Ordinates of Test Points in % of Chord
0	1	0
1—9	2—10	1,2 %
2—10	3—11	4,5
3—11	4—12	9
4—12	5—13	16
5—13	6—14	28
6—14	7—15	44
7—15	8—16	67
8—16	9—17	95









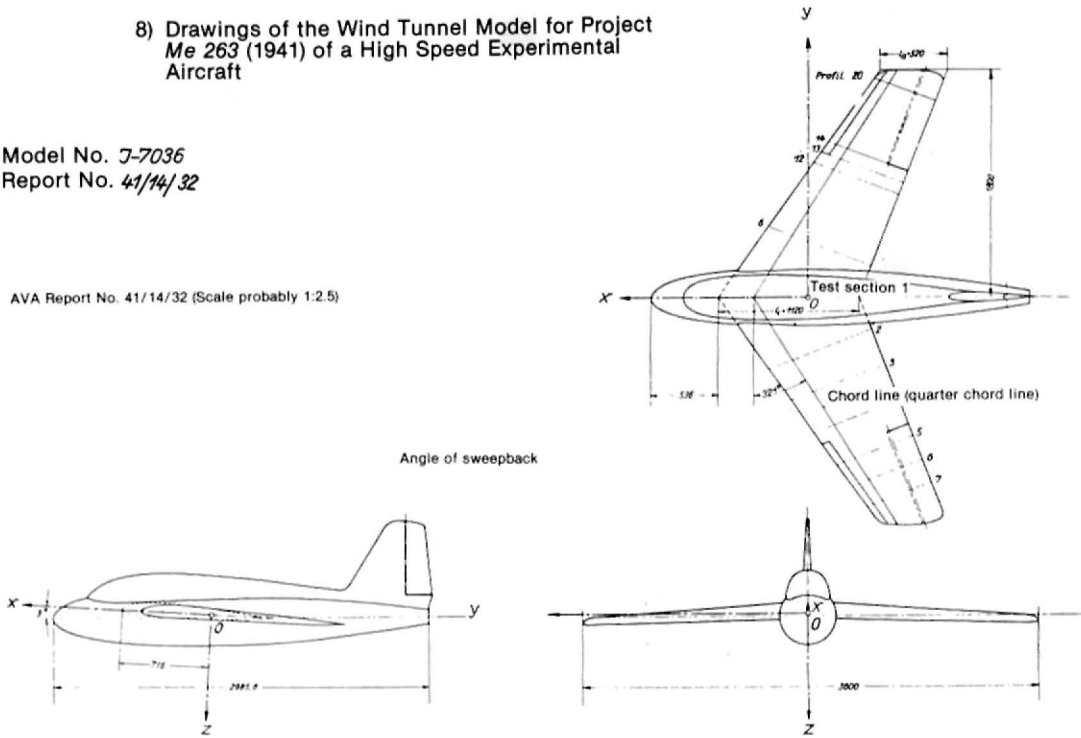
Aerodynamic Testing Center Göttingen

Wing Sections with Test Points

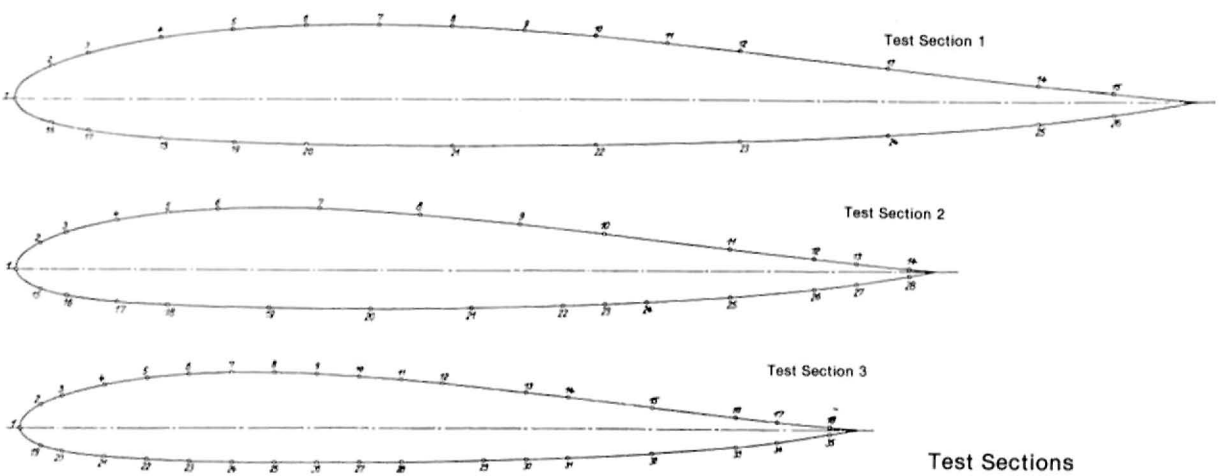
8) Drawings of the Wind Tunnel Model for Project *Me 263* (1941) of a High Speed Experimental Aircraft

Model No. *J-7036*
Report No. *41/14/32*

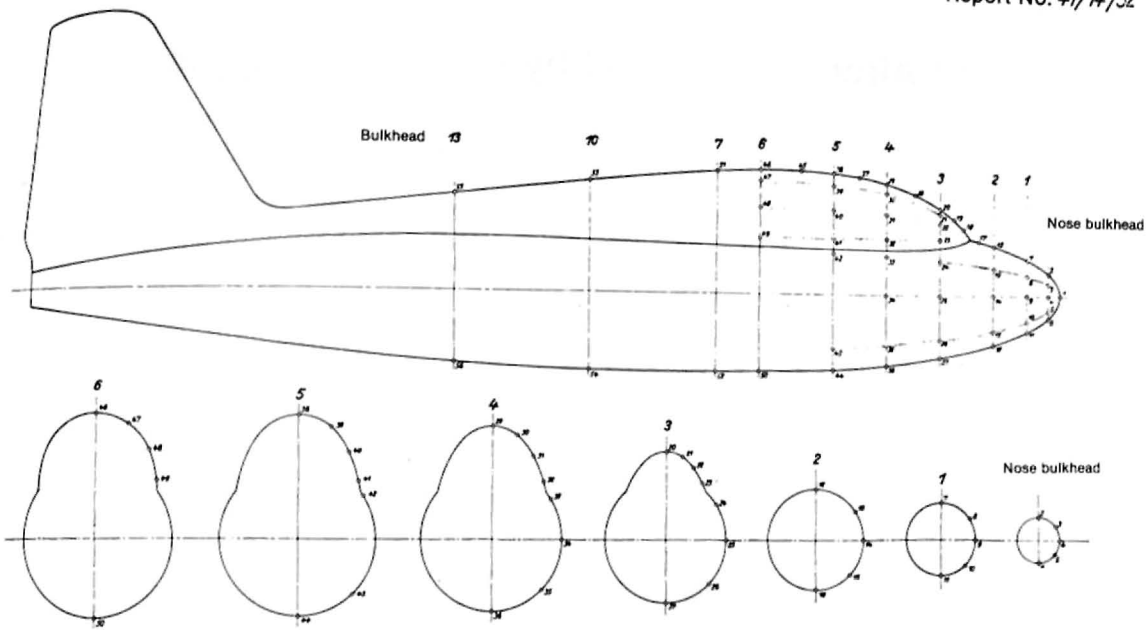
AVA Report No. 41/14/32 (Scale probably 1:2.5)



Model No. *J-7036* Report No. *41/14/32*

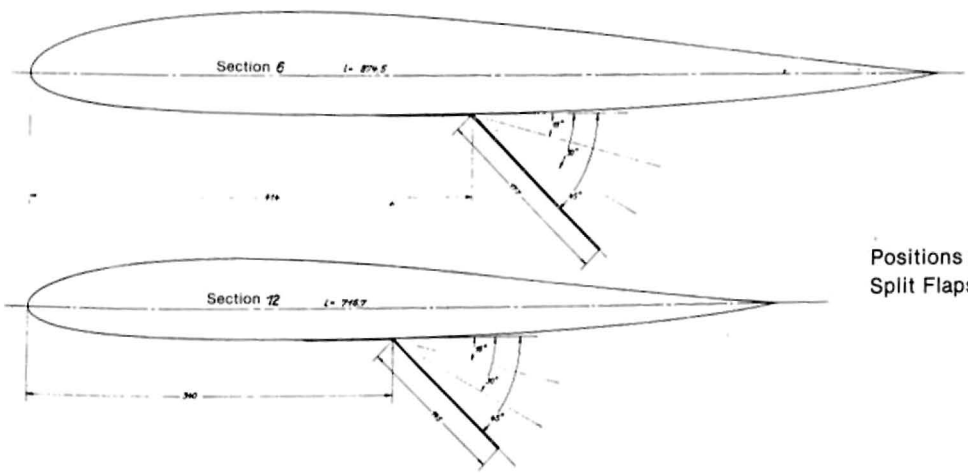


Test Sections

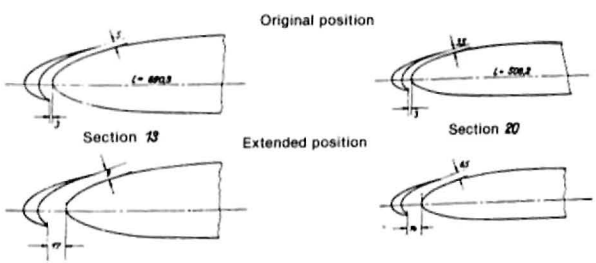


Fuselage with Test Points

Model No. J-7036 Report No. 41/14/32



Positions of Split Flaps



Slat positions

List of Aircraft Designed by Alexander Lippisch

a. Tailless High-wing Aircraft with Swept-back Wings (Stork et al.)

Year	Type	Built at	Span m	Length m	Wing Area m²	Empty Weight kg	Gross Weight kg	Remarks
1921–22	E 2	Lippisch-Espenlaub	11.0					Seat Glider
1925	Experiment	Lippisch-Steinmann	10.0 10.0	2.6 2.8	12.0 12.0	42	122	Seat Glider Project with 7.5 h.p. Ilo Boxer Engine
1927	Stork I	RRG	12.16	3.43	21.8			Experimental Glider
1927–28	Stork II	RRG	12.2	3.65	18.7			Wing without Dihedral
1928	Stork III	RRG	12.2	3.3	18.7			New Fuselage
1929	Stork IV	RRG	12.2	3.3	18.7			Changed Controls
1928–29	Rocket Propulsion	RRG	5.0	2.9	~5.2			Project for v. Opel
1929	Stork V	RRG	12.37	3.8	18.9	170	250	9 h.p. DKW Engine
1929	Stork VI	Project	~14					Enlarged Aspect Ratio
1930–31	Stork VII *Hans Huckebein*	Groenhoff-Lippisch	~12.0	~5.05	~20			24 h.p.
1932	Stork VIII	Philipp-Lippisch	14.0	3.15	~15			Also Flown with Tail
1933	Stork IX Tailless Glider	DFS	10.4	2.92	15.5			Training Glider
1933–34	Stork IX a	DFS	10.4	2.92	15.5			Training Glider, Covered Fuselage
1934	Stork IX b	DFS	10.4	4.29	15.5			30 h.p. Bristol Cherub
1936	Stork IX c	Project	11.07	3.94	~16.5			30 h.p. Bristol Cherub Changed Controls
1936	Stork X	Project						Radial Engine
1936	DFS 38-SMS	DFS	12.8	4.6				Radial Engine
1937	DFS 193	Project Flugzeugbau Halle	11.16	5.77	17.08	750	1065	Project with 240 h.p. Argus As 10 c

b. Tailless Low-wing Aircraft with Swept-back Wings

Year	Type	Built at	Span m	Length m	Wing Area m^2	Empty Weight kg	Gross Weight kg	Remarks
Work at RRG/DFS								
1928	Transatlantic Aircraft	Proposal						4 Engines
1929	Powered Aircraft	Wooden Model RRG	10.4	4.65	18	300		40 h.p. Projected
1930	Large Commercial Aircraft	Proposal						2 Engines Projected
1930	Delta I	RRG	13.24	4.25	25			Glider
1931	Delta I	RRG	13.24	4.25	25	320	520	36 h.p. Bristol Engine
1931	Mail Carrier	Project						2 In-line Engines
1932	Delta II	RRG	9.0	3.90	15.2			24 h.p. Ursinus Engine
1932-34	Delta III	Focke-Wulf	12.0	4.90	20.2			1st Version with Pusher Propeller 1×30 h.p.
1932	Cargo Plane	Project						2 Radial Engines
1932	Commercial Aircraft	Project	15.0	7.2	55.5	1900	4000	5×130 h.p.
1932	Bomber	Project						4 Engines
1932	Delta IV-F 3 *Wasp*	Fieseler	8.7	4.3	16.4	330		2×75 h.p. Pobjoy
1934	Delta III	Focke-Wulf	12.0	5.0	20.2			2d Version Tractor Propeller 1×30 h.p. Argus
1935	Delta IV a	DFS	8.7	4.51	16.4			1×75 h.p. Tractor Propeller
1935	Delta IV b	DFS	9.8	5.0	16.6	370	680	1×75 h.p. Tractor Propeller
1936	Delta IV c-DFS 39	DFS	10.21	5.06	17.4	390	700	1×75 h.p. Tractor Propeller
1937	Delta IV d *Project X*	(Heinkel)	9.45 8.85	5.2 5.25				1st Project Me 163 2d Project Me 163
1937	Delta V-DFS 40	DFS	12.0	5.1				1×100 h.p. Argus
1937	DFS 194	DFS	10.45	5.68	~17	~460		1×100 h.p. Argus, 1st Version
1937	Fighter	Proposal						1×? h.p.

Year	Type	Built at	Span m	Length m	Wing Area m²	Empty Weight kg	Gross Weight kg	Remarks
1939	P 01-116	Project	6.0	5.48				1 Turbine
1939–40	DFS 194	Rebuilt at Messerschmitt	10.4	6.4				2d Version 1×300 kg HKW RI
1939	P 04-107 a	Project	16.0	5.83				2×450 h.p. Argus As 410
1939	P 04-106	Project	16.0	5.83				2×1200 h.p. DB 601 E
1939–41	Me 163 A	Messerschmitt-Hirth	8.85	5.6	17.50	1450	2400	1×750 kg RII 203 b
1939	P 01-111	Project	7.5	6.6	19.0	2200	4270	1 Turbine
1940	P 01-112	Project	8.0	7.5				2 Turbines
1940	P 01-113	Project	9.0	6.75				1×TL 3302 or 3304
1940	P 01-114	Project	9.0	6.5	18.0	890	2250	1×HWK Rocket
1940	P 06	Project	11.0	6.74	20.0	1147	1564	1×450 h.p. As 410 A
1941	Me 263*	Project	9.0	7.49	19.5	2000		1×HWK Rocket
1941	P 04-114	Project	16.8	5.86				2×240 h.p. As 10 c
1941	P 01-115	Project	9.0	6.75				1×150 kg HWK Rocket 1 Turbine
1941	P 01-116	Project	9.0	7.06				1 Turbine
1941	P 01-116	Project	9.0	6.75				1×1500 kg HWK Rocket
1941	P 01-117	Project	9.0	7.65				1×1500 kg HWK Rocket
1941	P 01-118	Project	9.0	7.2				1×1500 kg HWK Rocket
1941	P 01-119	Project	9.0	7.2				1×1500 kg HWK Rocket
1941	P 05	Project	12.8	7.6	36.0			3×1500 kg HWK 509
1941	P 08	Project	50.6	15.35	300	30,000	90,000	1×750 kg HWK 4×4000 h.p. DB 615
1941	Li 163 S	Project	9.2	5.7				1×1500 kg HWK 509 A
1941–43†	Me 163 B	Messerschmitt-Klemm	9.3	5.92	19.6	1900	4300	1×1500 kg HWK 509 A
1941	FG 10	Project	8.7	6.2				1×? kg HWK
1941	P 09	Project	11.6	7.1				2×Turbines
1942	P 09	Project	10.0	7.4				2×1500 kg HWK Rockets
1941	P 010	Project	13.4	8.15				2×Turbines
1942	P 10	Project	16.0	9.85				1×2700 h.p. DB 606
1942	Me 265 ex P 10	Project + Mock-up	17.4	10.00	45.00	6300	11,000	2×1750 h.p. DB 603

Work at "Department L" of the Messerschmitt A. G. *(continued)*

Year	Type	Built at	Span m	Length m	Wing Area m²	Empty Weight kg	Gross Weight kg	Remarks
1942	Me 329	Project + Mock-up	17.5	7.72				2×1750 h.p. DB 603
1942	Me 163 C†	Project	9.33	5.82	19.6	1900	4300	1×1500 kg HWK 509 A
1942	Me 163 D†	Project	9.33	6.82	19.6	2000	4600	1×1500 kg HWK 509 A
1942	P 11 2-place	Project	13.00	7.5				2×750 kg Jumo 004 A
1942	P 11 1-place	Project	12.65	8.14	37.3	4005	7500	2×760 kg Jumo 004 B
1942	P 12	Project	11.00 14.10	7.00 7.60	30.00 50.00			1×TL 3303
1942	P 13	Project	12.80	9.40				2×1475 h.p. DB 605 B
1943	P 20	Project	9.30	5.73	17.30	2419	3383	1×1010 kg Jumo 004 C
1943	8-343	Project	~9.30		~17.30			1×1800 h.p. DB 603 (?)

*Not identical with *Ju 248-Me 263*
†According to *Me 163 B* Manual
‡Not identical with later types of the same designation

Work at Luftfahrtforschung Wien (Institute of Aeronautical Research, Vienna)

Year	Type	Built at	Span m	Length m	Wing Area m²	Empty Weight kg	Gross Weight kg	Remarks
1943	P 11-121	Project	10.6	6.8				2×1010 Kg Jumo 004 C
1943	P 11-Delta VI	1st Prototype started in Wood Construction	10.8	7.49			16,000	2×1010 kg Jumo 004 C 1st Prototype Only 2 Takeoff Assist Rockets
1944	P 12	Project						1 Liquid Ramjet Engine
1944	GB 3/L	Project	3.0	1.5	2.25		250	1 Liquid Ramjet Glide Bomb
1944	P 13 a-Delta VII	Project	6.0	6.7				1 Solid Ramjet Engine plus 2 Takeoff Assist Rockets
1944-45	DM 1-P13 a V 1	Akaflieg Prien	6.0	6.325		297	460	Experimental Glider
1944	P 13 b	Project	6.9	7.2				1 Solid Fuel Ramjet Engine
1945	P 14	Project						2×1300 Kg HeS 011
1945	P 15 *Diana*	Project	~10.0	~6.4	~21.2		3600	1×1300 kg HeS 011 A

c. Normal Type Aircraft (with Tail Unit)

Year	Type	Built at	Span m	Length m	Wing Area m²	Empty Weight kg	Gross Weight kg	Remarks
1921	*Falke*	Schweitzer-Lippisch	11.0					Glider
1921–22	*Ente* (Canard)	Espenlaub-Lippisch						Canard Type Glider
1922	*Alexander*	Weltensegler	~12					Enlarged Wing of *Falke*
1923	*Phoenix*	Weltensegler						Wing-controlled Glider
1923	*Bremen*	Stamer-Lippisch	13.00		17	130	200	Training Glider
1923	*Djavlar Annama -Hol's der Teufel*	Weltensegler-Schleicher	10.45	6.5	20			Training Glider
1925	*Baby*	Lippisch-Steinmann	9.5	5.0	17	75	155	Training Glider
1925	*Hangwind*	Lippisch-Steinmann	10.6	5.0	16	90	180	Training Sailplane Glide Ratio 1:14
1925	*Hangwind*	Lippisch-Steinmann	10.6	5.0	16	90	180	Sailplane with Auxiliary Motor
1925	V 3	Lippisch-Steinmann	16.4	5.9	18	126	206	Sailplane
1925	*Liliput*	Lippisch-Steinmann	7.7	4.8	12	90	170	1×7.5 h.p. Ilo Motor
1925	Type VIII	Project						
1926	R 1 *Zögling*	RRG	10.0	5.5	15.8			Primary Glider
1926	RII *Prüfling*	RRG	10.0	5.5	16			Intermediate Sailplane
1927–28	*Ente*	RRG	12.0	4.3	20.3			Canard Type for Rocket Tests
1928	*Trabant*	RRG						Sailplane for Airplane Tow
1928	RIII *Professor*	RRG and Others	16.1	7.0	18.6	166	246	Sailplane
1928	*Mannheim*	Schleicher	17.3		27.1	200	270 340	High-performance Sailplane. 2-place
1928	*Wien*	Kegel	19.1	6.5	18.6	168	248	High-performance Sailplane (with Jacobs/Pahorilli)
1929	2-Place Trainer	RRG						
1930	*Hangwind*	RRG						Sailplane
1930	*Fafnir*	RRG	19.0	7.76	18.6	200	315	High-performance Sailplane
1930–31	RV *Falke*	Different Companies and Groups	12.6	5.26	17.5			Intermediate Sailplane Glide Ratio 1:19
	RVa *Falke*		13.2	5.26				Enlarged Span

c. Normal Type Aircraft (with Tail Unit) *(continued)*

Year	Type	Built at	Span m	Length m	Wing Area m²	Empty Weight kg	Gross Weight kg	Remarks
1932	*Grüne Post*	Different Companies and Groups	10.0	5.48	13.5	110	190	Intermediate Sailplane Glide Ratio 1:16.5
1933	*Präsident*	DFS	16.0	6.59	18.1	170	290	High-performance Sailplane Glide Ratio 1:21
1933	*Obs-Urubu*	DFS	26.0	8.0	38	390	540	Sailplane for Meteorological Observation 2-Place Glide Ratio 1:27
1933-34	Maikäfer	Michelstadt Aircraft Co.	14.0	6.85	17.5	210	310	1×18 h.p. Köller Motor
1934	*Fafnir II-São Paulo*	DFS	19.0	7.91	19	270	350	High-performance Sailplane
1936	*Kormoran*	DFS	14.0	4.94	16.3			Experimental Glider with Forward Sweep

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